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PART I FINAL REPORT

TRACKING & DATA RELAY SATELLITE SYSTEM CONFIGURATION & TRADEOFF STUDY

II SYSTEM ENGINEERING

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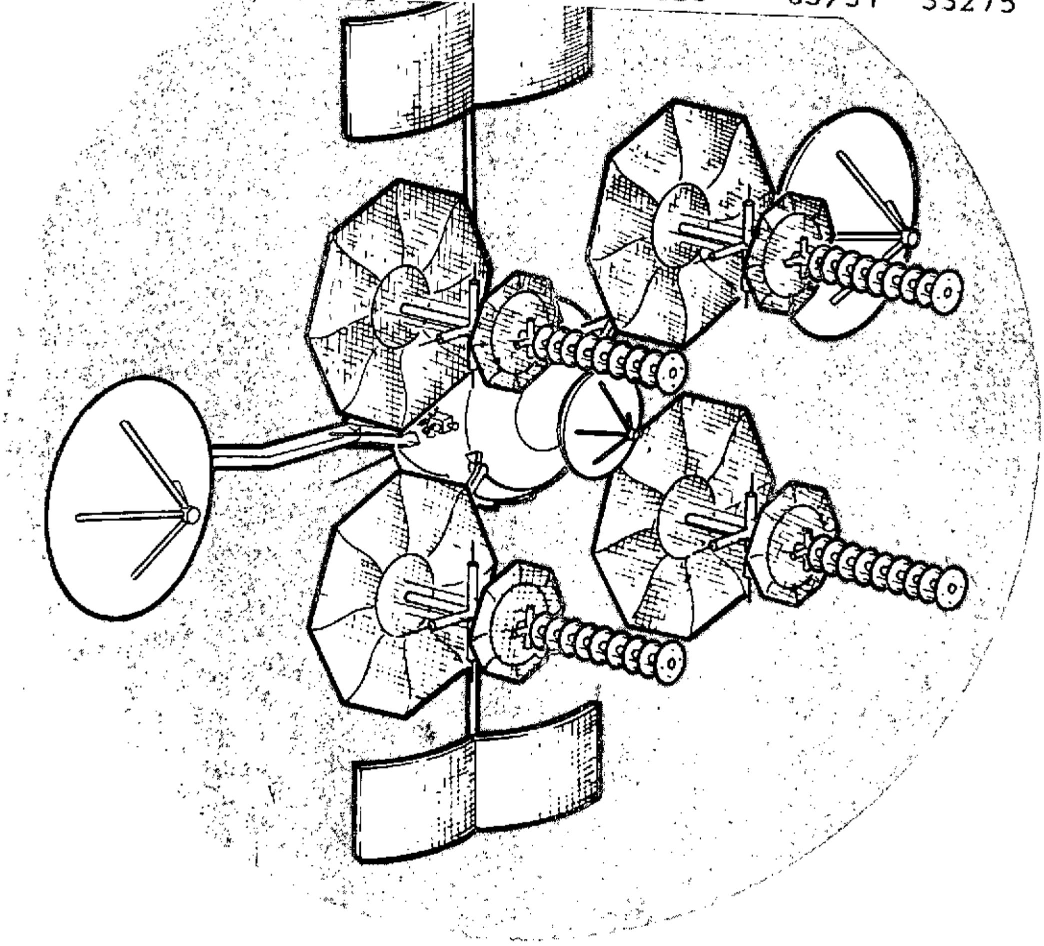

OCTOBER 1972

SUBMITTED TO
GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

IN ACCORDANCE WITH
CONTRACT NAS5-21705

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PART I FINAL REPORT

TRACKING & DATA RELAY SATELLITE SYSTEM CONFIGURATION & TRADEOFF STUDY

VOLUME II
SYSTEM ENGINEERING

T. E. Hill
TDRS STUDY MANAGER

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FOREWORD

This report summarizes the results of Part I of the study conducted under Contract NAS5-2107, Tracking and Data Relay Satellite Configuration and Systems Trade-off Study - 3-Axis Stabilized Configuration. The study was conducted by the Space Division of North American Rockwell Corporation for the Goddard Space Flight Center of the National Aeronautics and Space Administration.

The study is in two parts. Part I of the study considered all elements of the TDRS system but emphasized the design of a 3-axis stabilized satellite and a telecommunications system optimized for support of low and medium data rate user spacecraft constrained to be launched on a Delta 2914. Part II will emphasize upgrading the spacecraft design to provide telecommunications support to low and high, or low, medium and high data rate users, considering launches with the Atlas/Centaur and the Space Shuttle.

The report consists of the following seven volumes.

1.	Summary	SD 72-SA-0133-1
2.	System Engineering	SD 72-SA-0133-2
3.	Telecommunications Service System	SD 72-SA-0133-3
4.	Spacecraft and Subsystem Design	SD 72-SA-0133-4
5.	User Impact and Ground Station Design	SD 72-SA-0133-5
6.	Cost Estimates	SD 72-SA-0133-6
7.	Telecommunications System Summary	SD 72-SA-0133-7

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R.H. French	"	Operations Analysis
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2.0 SYSTEM ENGINEERING

The topics of Mission Analysis, Network Operations and Control, and System Reliability are covered in this report. Mission analysis of the TDRS includes orbital analysis, launch vehicle performance, satellite deployment, and system sensitivity to variation in orbital, apogee motor and inclination parameters. Mission profiles and timelines are presented for launch, transfer orbit and deployment phases of the mission. Next, under Network Operations and Control, a functional analysis is performed and functional flow diagrams are shown to the third and fourth levels. A representative flow of operational phase functions is presented in tabular form. The primary TDRSS elements are identified and the interfaces between them indicated. Finally, a system reliability analysis shows the relationship between satellite reliability and the probability of having either one or two spacecraft in full operation at the end of five years as a function of the original number of satellites.

2.1 MISSION ANALYSIS

This section is organized with the data, conclusions, and recommendations on inclination, spacing, and geographic location of the TDRS satellites presented first in "Network Configuration." A discussion of Operational Plans follows, describing delivery to orbit and stationkeeping, including tradeoff data and a description of the baseline plan delivery sequence and the assignment of orbit and station locations. Performance and performance sensitivity of the baseline deployment and delivery system are then described. From this information, the TDRS on-orbit weight capability is determined. Finally, a mission profile and timelines are developed for the launch and deployment mission phases.

2.1.1 Network Configuration

This part of the mission and trajectory analysis is concerned with the tradeoffs underlying the selection of TDRS orbit, inclination, spacing, and location. The parametric relationships are presented first, followed by the baseline conditions.

2.1.1.1 TDRS Location and Inclination

The selection of the TDRS location and orbit inclination is based on three basic performance factors: payload weight, visibility of the ground station, and user satellite coverage. To increase user spacecraft coverage, it is desirable to increase satellite spacing. To increase satellite spacing, a low final TDRS orbit inclination is desirable. However, payload weight increases with increased orbit inclination, allowing for possible increases in relay capability. Figure 2-1 is a composite graph which shows the relationship of these basic factors. The payload capability is based on the use of a

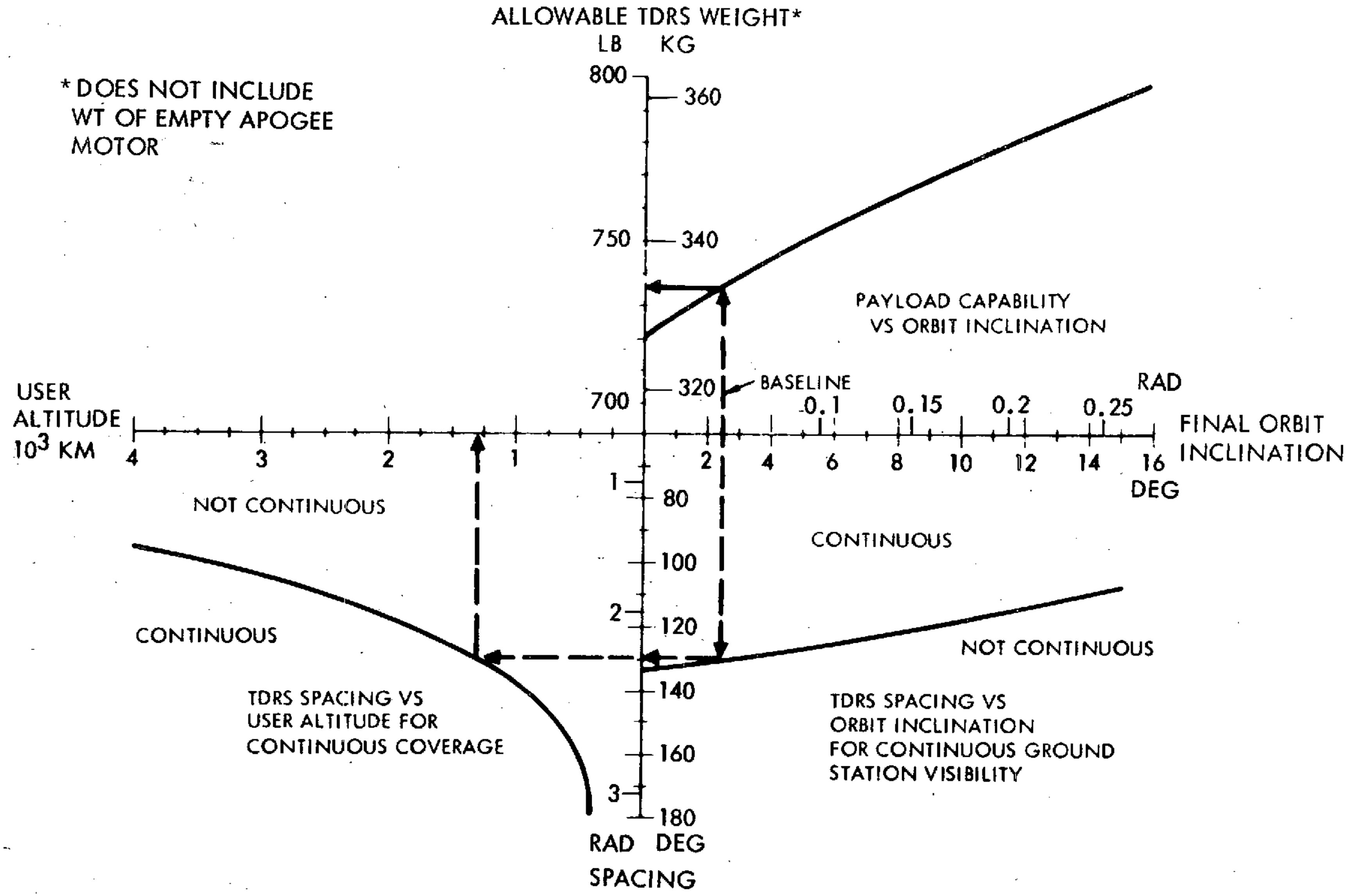


Figure 2-1. Inclination Trade Offs

Delta 2914, launched due east from KSC, with a modified Thiokol TE-M-616 apogee motor. The ground station visibility curve is based upon a minimum elevation angle at the ground station of 10° (.17 rad), and a ground station latitude of 35.2 degrees.

As a result of unique and creative telecommunications system and spacecraft designs the TDRS concept developed in this study provides capabilities considerably greater than required by the SOW specification. The increase in relay capabilities, provided by increasing the orbit inclination, was weighed against the increase in size of the user spacecraft cone of exclusion, and in light of the impressive relay capacity provided by the baseline design, the decision was reached to maximize user spacecraft coverage by placing the TDRS in a low-inclination orbit.

As can be seen from Figure 2-1, for a final orbit inclination of 2.5° (.043 rad), which was selected for the baseline, the TDRS can weight 734 lb (333 kg) plus the weight of the empty apogee motor. Continuous ground station visibility can be maintained with a TDRS spacing of 130° (2.27 rad). This provides continuous visibility of user satellites above 1275 kilometers (688 nautical miles). The minimum user altitude for continuous coverage increases rapidly as spacing is reduced below 130° (2.27 rad) as occurs when the inclination is increased to obtain more payload.

The region where user satellites are invisible to either TDRS satellite for the baseline locations is shown in Figure 2-2 for satellite spacings of 125° (2.18 rad) and 130° (2.27 rad). Figure 2-3 shows the variation in this cone of exclusion for closer spacings. Figure 2-4 shows the effect of orbit inclination ground elevation angle, and ground station latitude on the maximum permissible TDRS spacing to maintain ground station visibility.

The satellite final orbit inclination is perturbed by the lunar and solar gravitational fields at a rate of approximately .75° (.013 rad)/year (Figure 2-5). Judicious selection of launch time will cause the orbit inclination to start decreasing, pass through zero, and then increase. Figure 2-5 shows that after six years the inclination is still below 2.5° (.043 rad). This occurs even with a 25° (.43 rad) variance from the optimum ascending node position. This variance is equivalent to a 1.66-hour launch delay.

2.1.1.2 Booster/Apogee Motor Capability

The TDRS weight that can be delivered to synchronous orbit by a given booster is a function of the inclinations of the transfer orbit and of the final TDRS orbit. The required plane change between the parking orbit and the final TDRS orbit can be divided between the perigee impulse (injection into the transfer orbit) and the apogee impulse (injection into synchronous orbit). The optimal apportionment of the plane change and, thus, the inclination of the transfer orbit, depends upon the required final orbit inclination and the characteristics of the apogee motor and the launch vehicle. In order to avoid off-loading of the launch vehicle and the use of ballast, the weight at apogee motor ignition required to provide the necessary delta V at apogee must be matched to the injection capability of the launch vehicle.

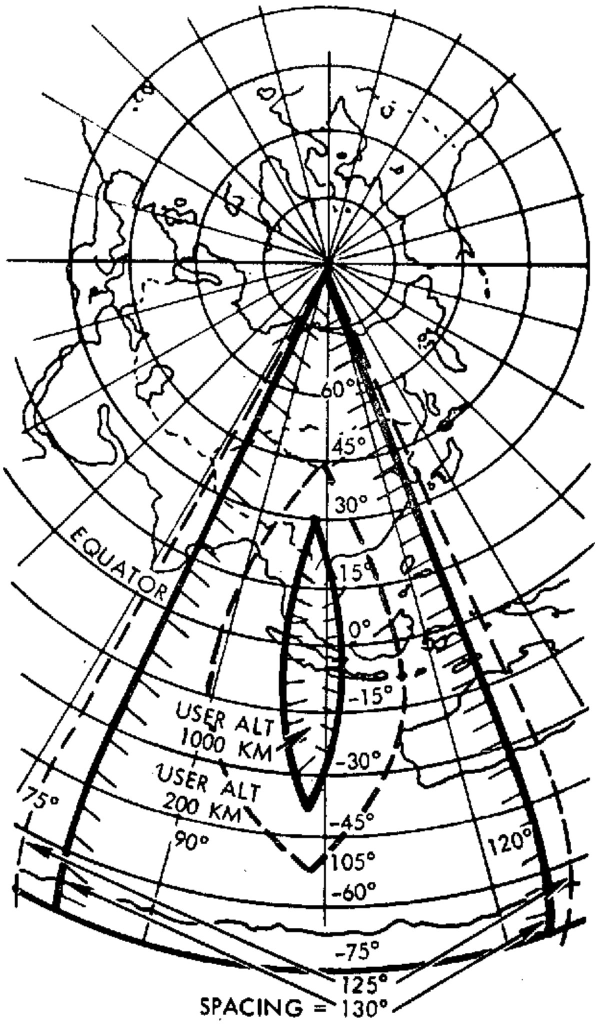


Figure 2-2. Cones of Exclusion

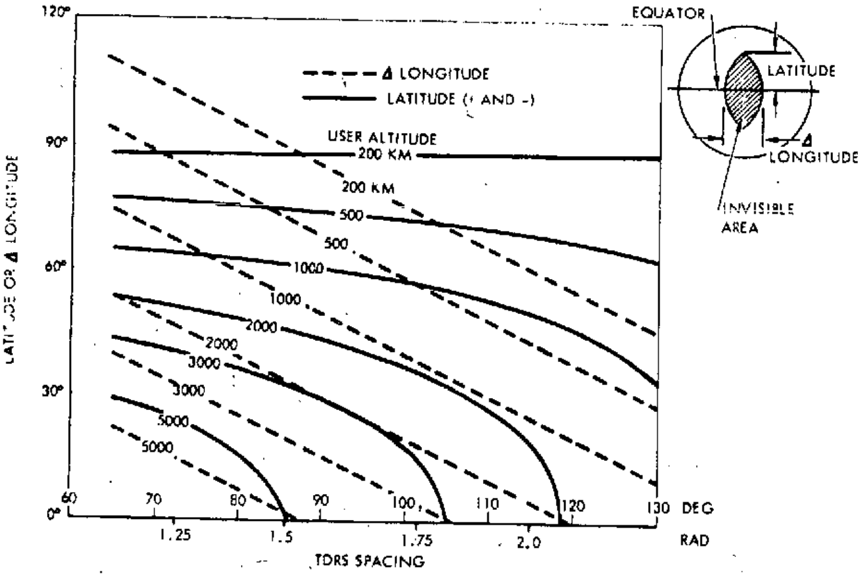


Figure 2-3. Area of Invisibility

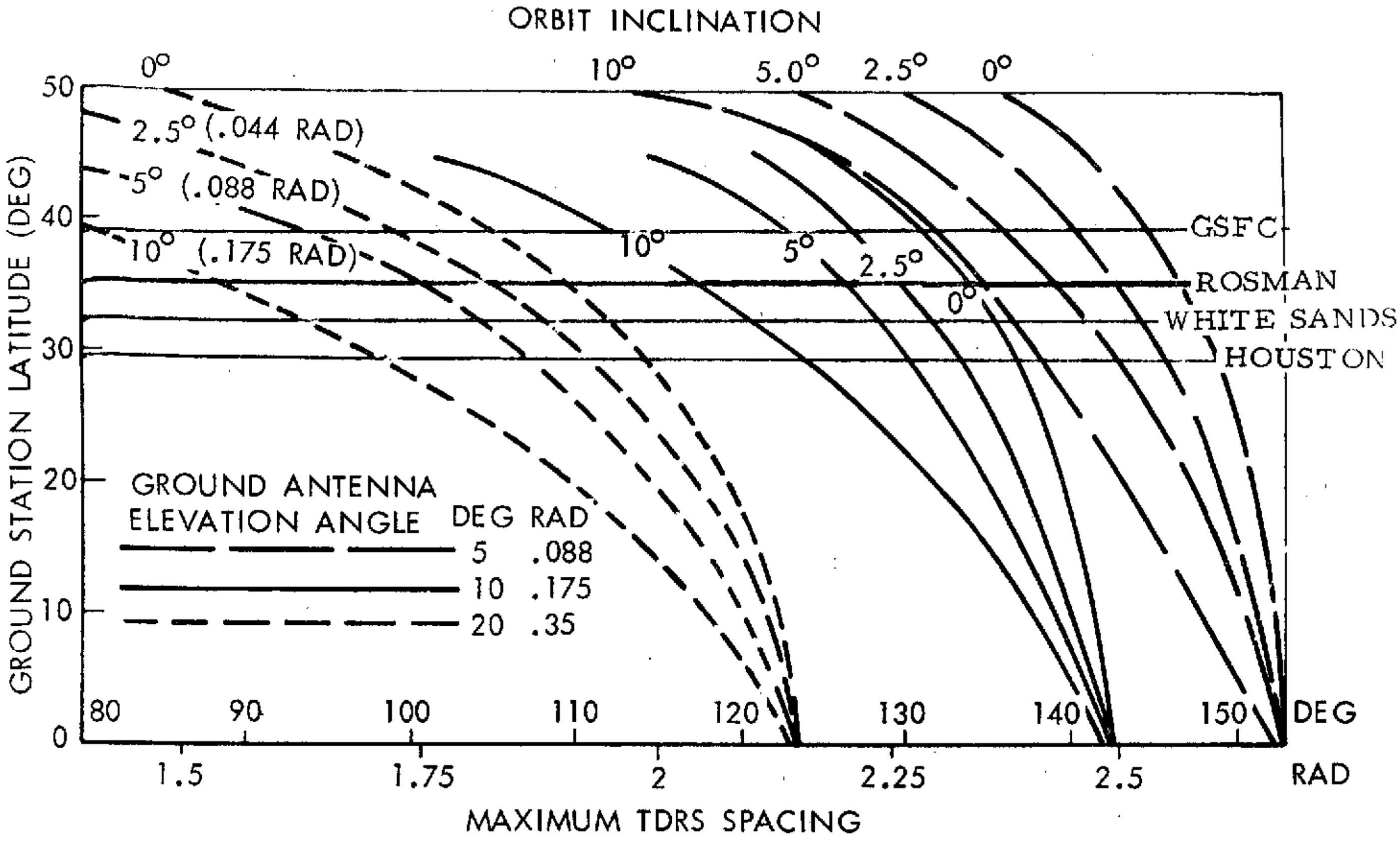


Figure 2-4. Maximum TDRS Spacing

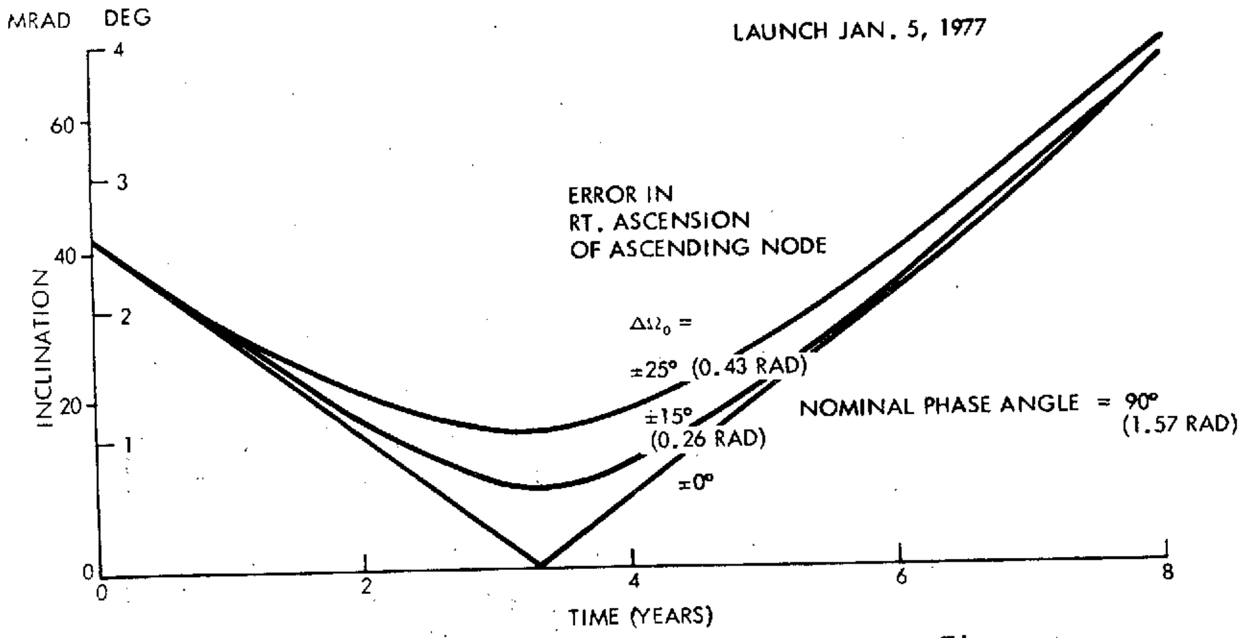


Figure 2-5. Variation of Orbit Inclination vs Time

Figure 2-6 presents the capability of the Delta 2914 launch vehicle as a function of transfer orbit inclination. Each value of transfer orbit inclination defines a plane change requirement for the apogee motor, which is equal to the transfer orbit inclination minus the final required TDRS orbit inclination. Figure 2-7 shows the weight of the apogee motor and payload versus transfer orbit inclination for various values of apogee motor propellant loading based on the TE-M-616 apogee motor and a 2.5° (.043 rad) final TDRS inclination. The intersections of these curves, with the launch vehicle payload curve of the previous figure, form a curve of points fulfilling the aforementioned matched condition. The apogee motor payload and propellant weights corresponding to these intersections are plotted in Figure 2-8; the maximum payload is 734 lb (333 kg) plus the 50-lb (22.7 kg) empty apogee motor case and 8-lb (3.6 kg) burned-out insulation. The optimum transfer orbit inclination is 27° (.47 rad) with 692 lb (315 kg) propellant loading for the apogee motor. The peak in the payload curve is a result of the decreasing slope of the launch vehicle payload curve in the presence of the relatively constant downward slope of the apogee motor curve. The values shown are the capability to synchronous orbit. The TDRS baseline operational mode injects the spacecraft into a subsynchronous drift-bias orbit and permits an increase in payload, as described in Section 2.1.4.

The optimum transfer orbit inclination can also be established for other final orbit inclinations. In Figure 2-9, the payload peak shifts gradually toward higher values of transfer orbit inclination as the TDRS final orbit inclination increases. Figure 2-9 shows the associated values of propellant weight. The maximum payload and associated propellant weight are shown in Figure 2-10 as a function of final orbit inclination, using the optimum transfer orbit inclination. Although an increase in TDRS payload is attainable at higher final orbit inclinations, the coverage of the TDRS is correspondingly reduced, as shown in Figure 2-1.

As the baseline 3-axis design does not require the added payload that is possible at higher inclinations [approximately 5 lb (2.3 kg)/degree], the inclination was selected to maximize performance. The initial inclination was selected as 2.5° (.043 rad), reducing in approximately three years to zero, and then increasing again.

2.1.2 TDRS Operational Plan

This section pertains to the TDRS functions of launch, drift orbit to longitudinal station, stationkeeping, and longitudinal station change. As in the previous section, the parametric data are presented first, after which the recommended baseline is described. The first operational phase to be considered is the launch and delivery phase.

2.1.2.1 Launch

The TDRS is launched eastward from KSC by a Delta 2914. The TDRS departs from the transfer orbit at apogee using a solid apogee motor. There are several tradeoffs involved in the selection of which apogee to use as the departure points. Principal factors are time and the location of each apogee relative to the final TDRS station.

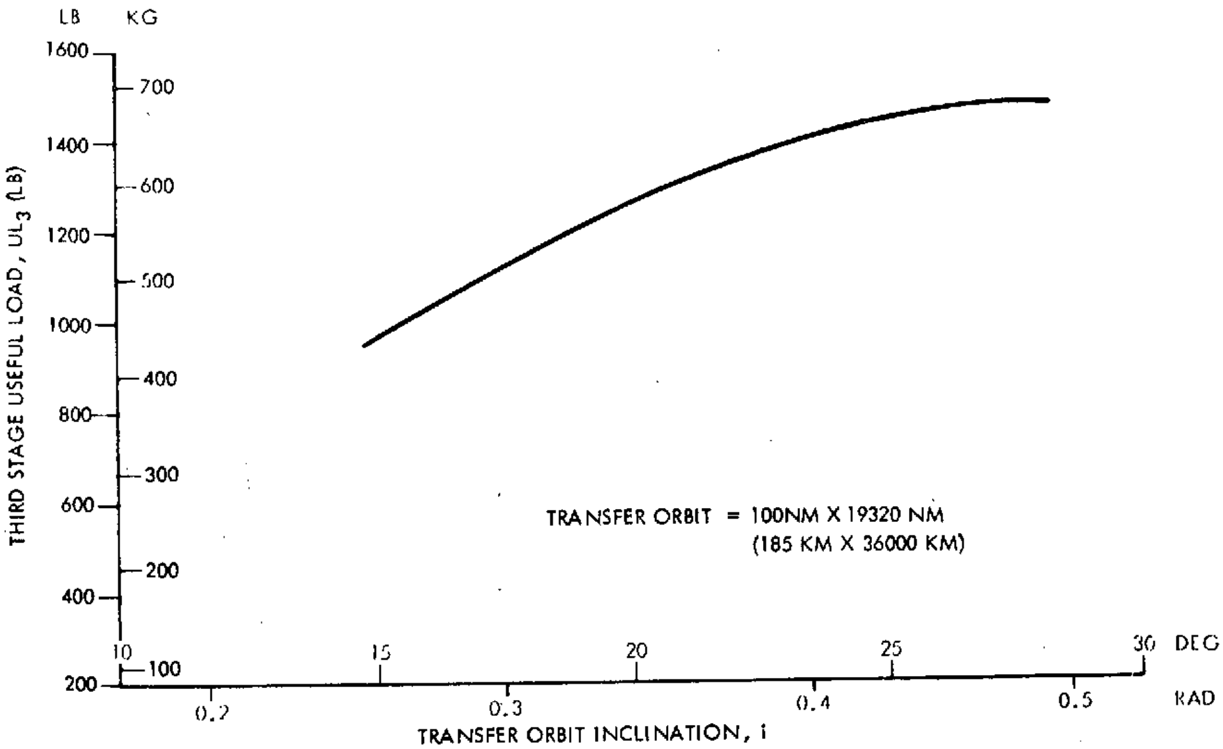


Figure 2-6. Delta 2914 Synchronous Transfer Capability ETR

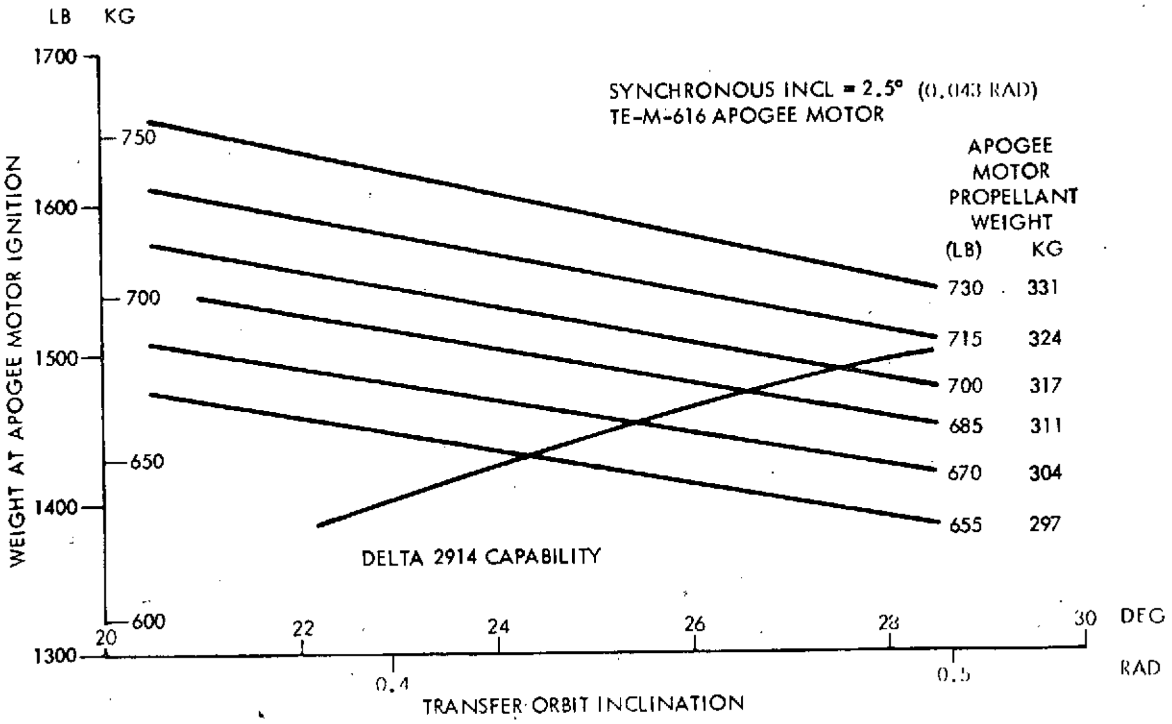


Figure 2-7. Weight of Apogee Motor Plus Payload

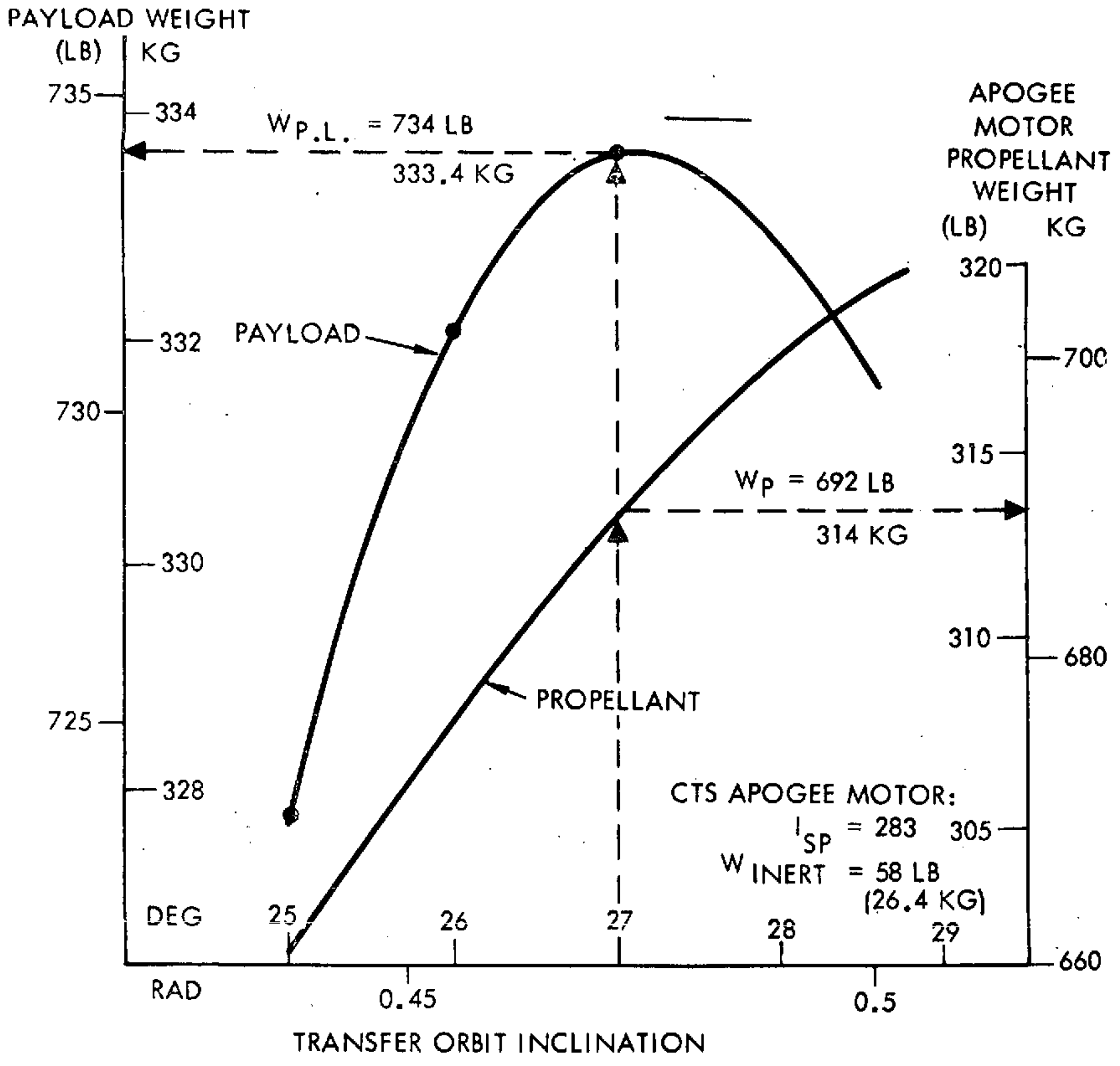
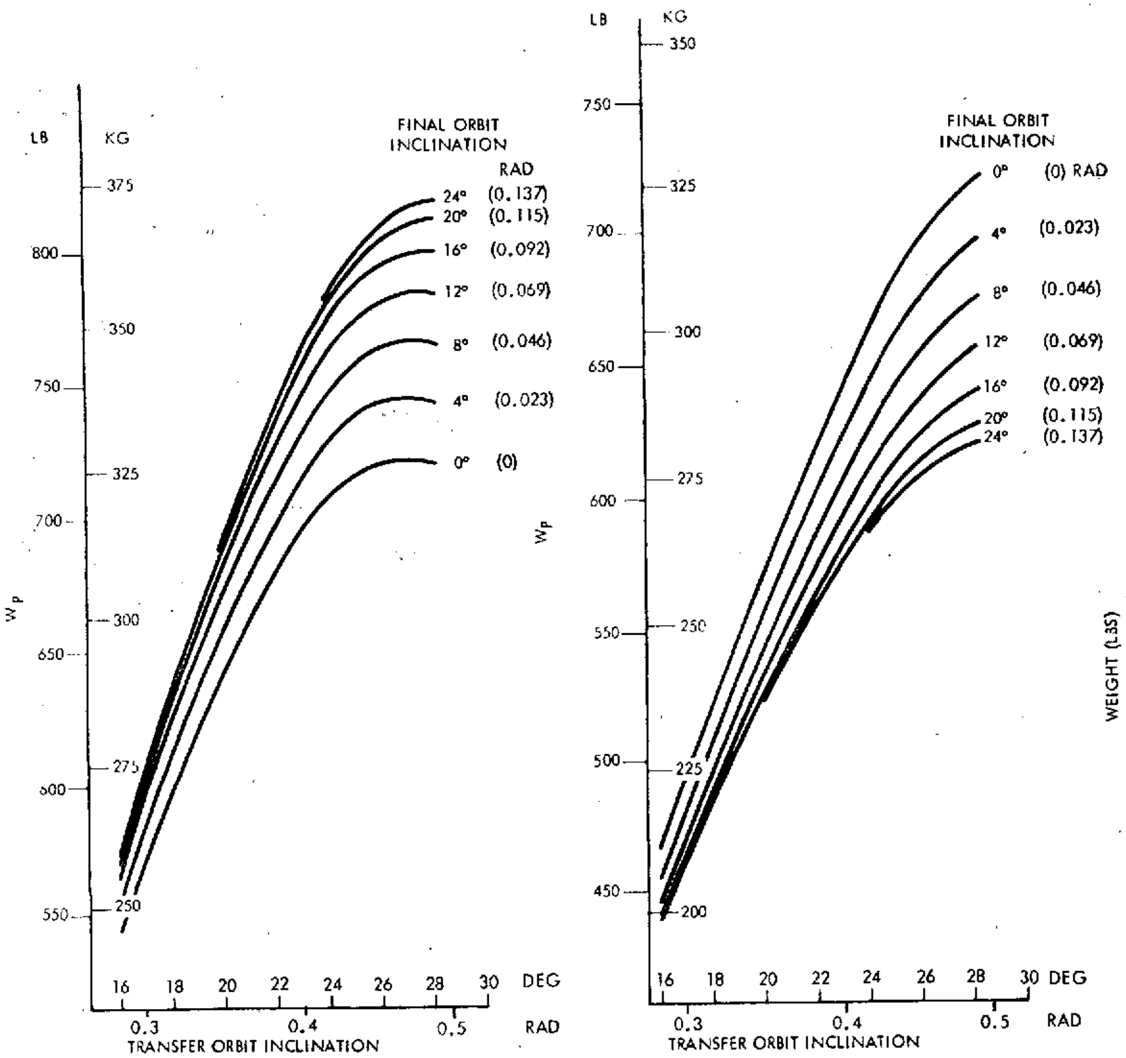


Figure 2-8. Delta 2914 Payload to Synchronous Orbit - 2.5° (.043 RAD) Inclination



(a) Payload Weight (b) Propellant Weight

Figure 2-9. Payload & Propellant Weight as a Function of Transfer & Final Orbit Inclination

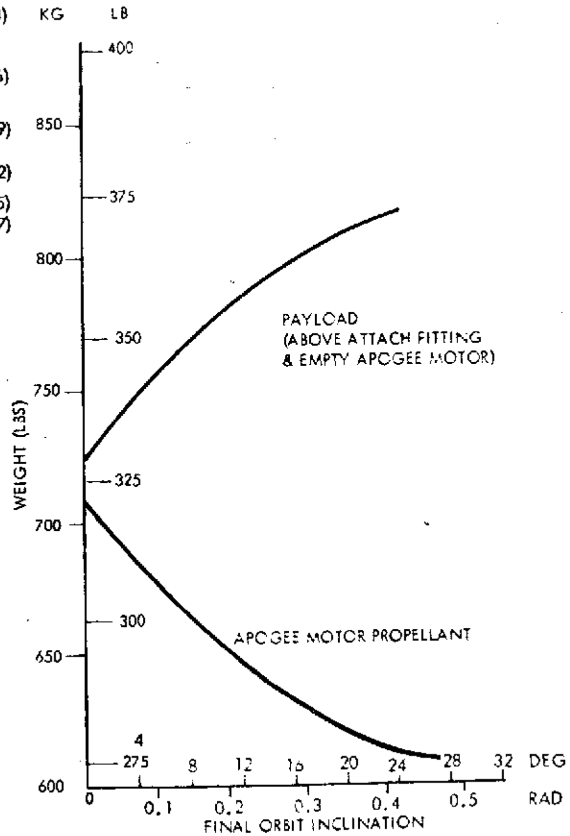


Figure 2-10. Payload Capability & Apogee Propellant vs Orbit Inclination Delta 2914

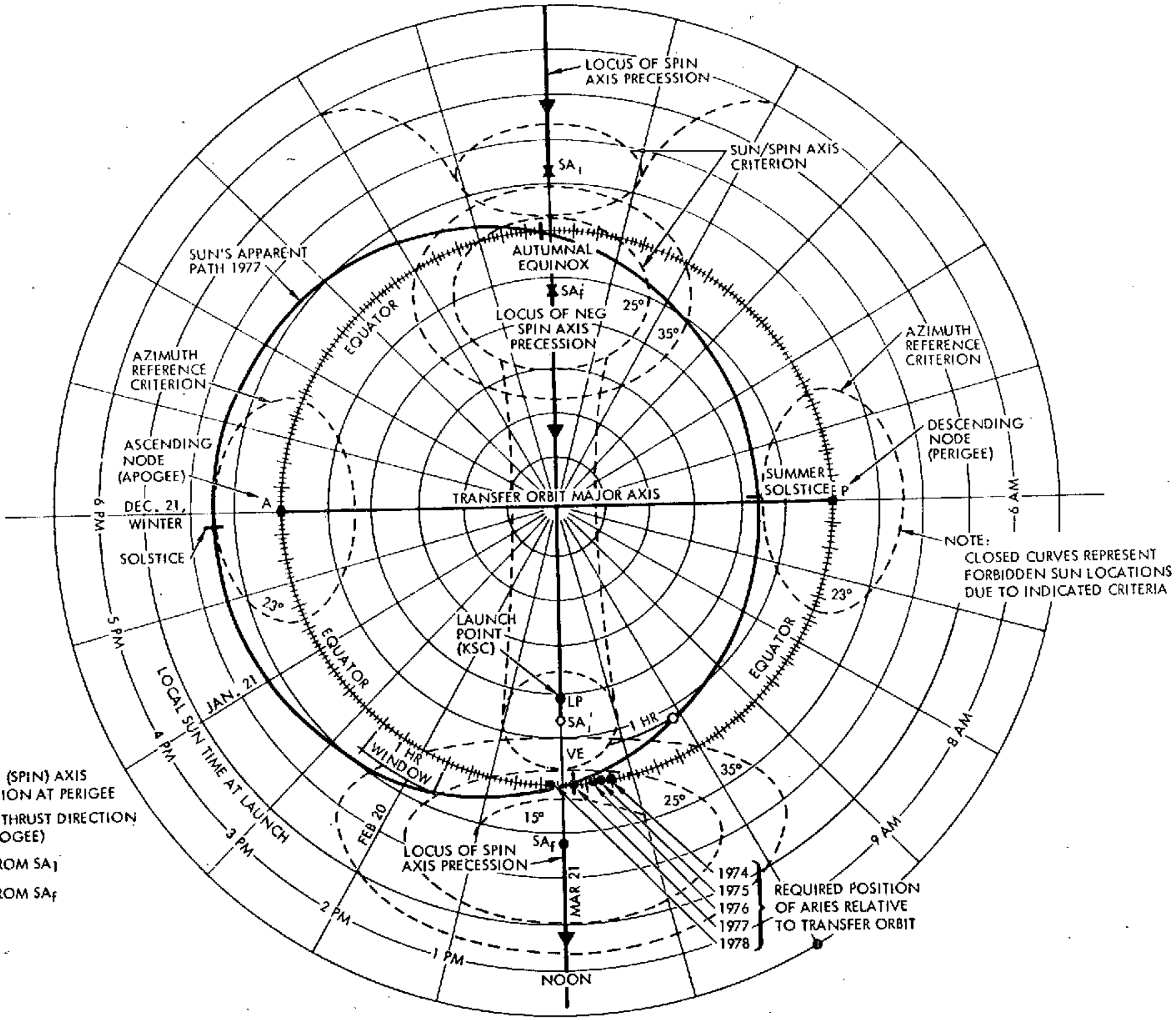
Two geometric criteria affect the launch date and time for a TDRS mission. The ascending node (and major axis) of the transfer ellipse must have the appropriate inertial position to cause the TDRS synchronous orbit inclination to start its variation in the negative direction; and the sun must be located relative to the spacecraft to be useful as a directional reference and to provide adequate power during transfer orbit. The method used for determining the inertial orientation of the transfer orbit is described in Appendix 2.A. The results of that analysis are applied in the following discussion, which also shows how the appropriate relative location of the sun can be assured.

The directions of the spin axis, the sun, Aries, and the satellites are shown in vector form in the polar system of Figure 2-11. Figure 2-11 also shows the position of Aries, relative to the mission geometry, which satisfy the conditions on inclination perturbation for the years 1974 through 1978. Also shown is the sun's apparent path during 1977. The contours (dash-lines) show regions from which the line of sight to the sun may be excluded without seriously limiting the launch opportunities. The attitude determination system must be compatible with these contours. The sun/spin axis angle must be large enough for the sun sensor to provide meaningful "pip" data, and the sun/vertical angle at perigee and apogee must be large enough to provide good azimuth data. The sun/spin axis angle is shown for 15°(.26 rad) minimum except at apogee burn, where contours are shown for 15°(.26 rad), 25°(.43 rad) and 35° (.61 rad). The sun/vertical angle at apogee is shown for 23° (.4 rad).

Figure 2-11 shows that for a requirement of a minimum 25°(.43 rad) sun/spin axis angle at apogee, launches are prohibited for 15 days each side of the vernal equinox and the autumnal equinox. If the 35°(.61 rad) contour is required the prohibitive period doubles; if an angle of 18°(.31 rad) or less is acceptable, the launch date is unrestricted. The relative positions of Aries in Figure 2-11 correspond to the first day of each year. The assumption that Aries remains fixed for every position of the sun is only an approximation. It is a fairly good approximation, however, as the point moves only about 5° (.087 rad) over a year's time.

Allowable launch times can also be found from Figure 2-11. The launch point is approximately 90°(1.57 rad) behind (CW from) the transfer orbit perigee at a latitude of 28.5°(.5 rad). The local sun time at launch is represented by the longitudinal distance between the sun's meridian and that of the launch point (at about 15 degrees/hour). Local noon corresponds to zero angular distance. The size of the launch window depends on how close the selected launch date is to the time of an equinox. For example, for the 25°(.43 rad) contour, if April 19 is selected for the launch date, the nominal launch time is slightly after 10:00 a.m., and the sun is at 11 degrees declination (circle on sun trace). A one-hour delay in launch would carry the sun to the boundary of a forbidden zone. The launch window is, therefore, the hour between 10:00 a.m. and 11:00 a.m. On the other hand, the launch window for launches before March 9 is much greater than one hour.

The launch window, from the standpoint of sun location, is the time represented by the angular distance between contours at the sun's latitude



SA_I = THRUST (SPIN) AXIS DIRECTION AT PERIGEE

SA_f = FINAL THRUST DIRECTION (AT APOGEE)

SA_I' = 180° FROM SA_I

SA_f' = 180° FROM SA_f

Figure 2-11. Launch Constraints Polar Plot for the given launch date. The true launch window is obtained by superimposing the range of launch times tolerable from the standpoint of the inclination perturbation discussed in paragraph 2.1.1.2.

2.1.2.2 Transfer Orbit

The TDRS is injected into the transfer orbit at the first descending node of the parking orbit, as in previous geosynchronous missions. This places minimum reliance on the launch vehicle reliability and does not impose a serious additional reliability burden on the TDRS spacecraft.

Figure 2-12 shows the visibility of the TDRS to STDN tracking stations during the transfer orbit. If Tananarive, Rosman and Orroral are used to track and command the TDRS during the transfer orbits through the third apogee, visibility is maintained for the entire time except for 165 minutes at the second perigee and 38 minutes at the third perigee. If Guam is used instead of Orroral, the 165-minute period is reduced to 118 minutes. These times are considered satisfactory.

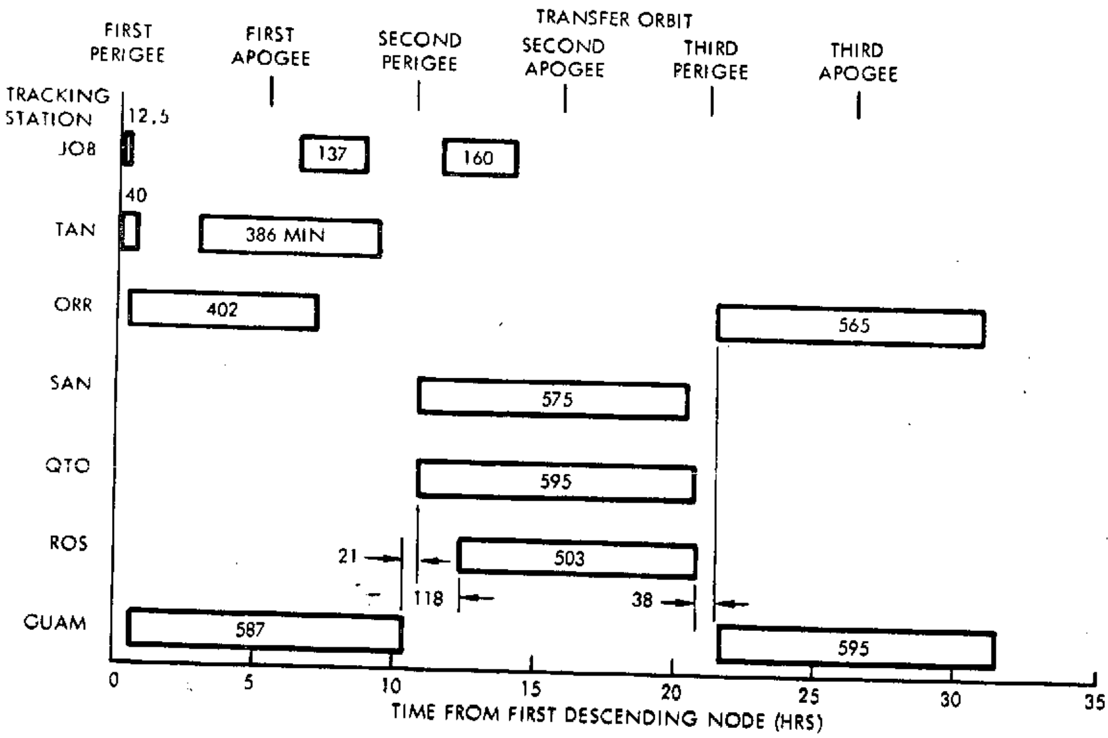


Figure 2-12. Tracking Station Visibility

The baseline transfer orbit has an apogee at synchronous altitude and the apogee motor burns out at a velocity slightly below geosynchronous to provide an eastward drift of 5° (.87 rad)/day. The transfer orbit inclination is 27° (.47 rad). Plane changes of 1.3° (.023 rad) and 24.5° (.43 rad) are made at perigee and apogee, respectively, to provide a nominal 2.5° (.043 rad) final orbit inclination.

Synchronous orbit injection occurs at the second or third apogee of the transfer orbit. This provides ample time for tracking, orbit determination, and vehicle precession; and places each TDRS in a position to the west of its assigned station.

Figure 2-13 shows the ground trace of the TDRS during parking and transfer orbits, and the locations of the first five apogees, the tracking stations, and final TDRS locations.

The longitudinal axis of the TDRS during the transfer orbit must precess from its position at perigee to the orientation required for the apogee impulse. The thrust vector lies in the local horizontal plane for both impulses. The horizontal plane at perigee is parallel to the horizontal plane at apogee. The plane of rotation from the perigee orientation to the apogee orientation is, therefore, this same plane. Figure 2-14 shows the thrust vector orientation at both apsides and the associated velocity vectors. The vehicle is initially oriented at an angle of 20.2° (.35 rad) below the equator and precesses during the transfer through 140.5° (2.45 rad) to an angle of 19.3° (.34 rad) below the equatorial plane.

The perigee impulse for the transfer is computed as follows:

$$\Delta V_x = V_p \text{ COS } i_t - V_o \text{ COS } i_o$$

$$\Delta V_y = V_o \text{ SIN } i_o - V_p \text{ SIN } i_t$$

$$\Delta V_{perigee} = 8139 \text{ ft/sec (by Delta 2914 third stage)} \; (2471 \text{ m/sec})$$

and the apogee impulse is computed similarly,

$$\Delta V_x = V_f \text{ COS } i_f - V_a \text{ COS } i_t$$

$$\Delta V_y = V_f \text{ SIN } i_f - V_a \text{ SIN } i_t$$

$$\Delta V_{apogee} = 5718 \text{ ft/sec (by apogee motor)} \; (1742 \text{ m/sec})$$

where

V_o = parking orbit velocity, 25,582 fps (7797 m/sec)
V_p = perigee velocity, 33,656 fps (10,258 m/sec)
i_o = parking orbit inclination, 28.3 degrees (.5 rad)
i_t = transfer orbit inclination, 27 degrees (.47 rad)
V_a = apogee velocity, 5233 fps (1595 m/sec)
V_f = final synchronous velocity, 10,088 fps (3075 m/sec)
i_f = final orbit inclination, 2.5 degrees (.043 rad)

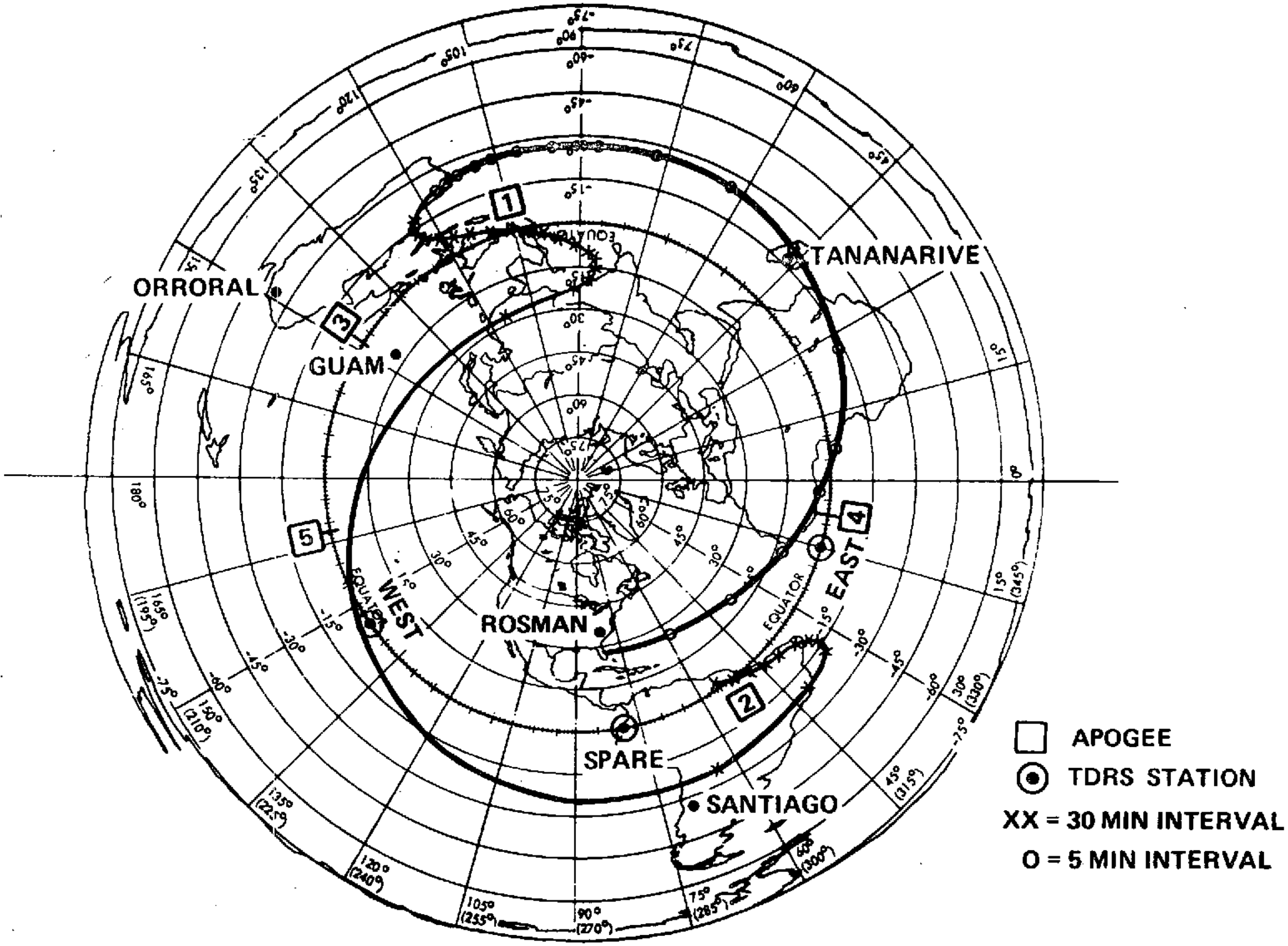


Figure 2-13. Ground Trace and Final Stations

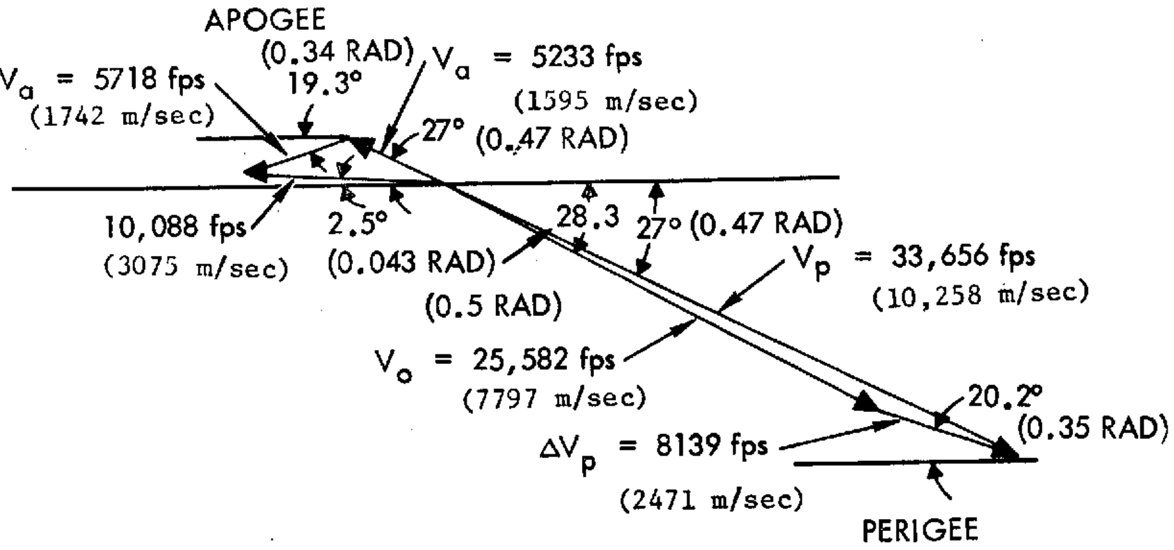


Figure 2-14. Thrust Vector Orientation and Velocity Vectors

2.1.2.3 Synchronous Orbit Injection and Station Acquisition

The impulse provided at the transfer orbit apogee injects the TDRS into a geosynchronous or near-geosynchronous orbit at the final orbit inclination and has both an inplane and an out-of-plane component. The in-plane component places the vehicle in a drift orbit with an easterly motion. If the TDRS is injected at exactly synchronous velocity (drift rate equal to zero), the on-board propulsion system (monopropellant hydrazine) must initiate and stop the drift to station. If the TDRS is injected with a velocity biased slightly below synchronous, it will have a "built-in" drift, and the on-board propulsion system must only stop the drift at the appropriate station. The advantages of biased injection are described in detail in Appendix 2.B. The variation in payload weight with the amount of drift is also discussed in Appendix 2.B.

For each 1° (.017 rad)/day drift rate, .921 lb (0.42 kg) of hydrazine is required to stop each satellite at its assigned station.

Figure 2-15 shows the effect of drift rate on (1) time to station for the three TDRS satellites, and (2) net "payload loss," apogee motor propellant reduction, and increase in on-board hydrazine. The net "payload loss" is defined as the loss in dry weight of the TDRS and is the difference between the required hydrazine and the reduced apogee propellant after the "drift bias" mode has been selected. For the drift range considered, the effect on payload is negligible. In using the drift bias mode, an actual gain in dry payload of about 4 pounds (1.8 KG) results, as described in Appendix 2.B.

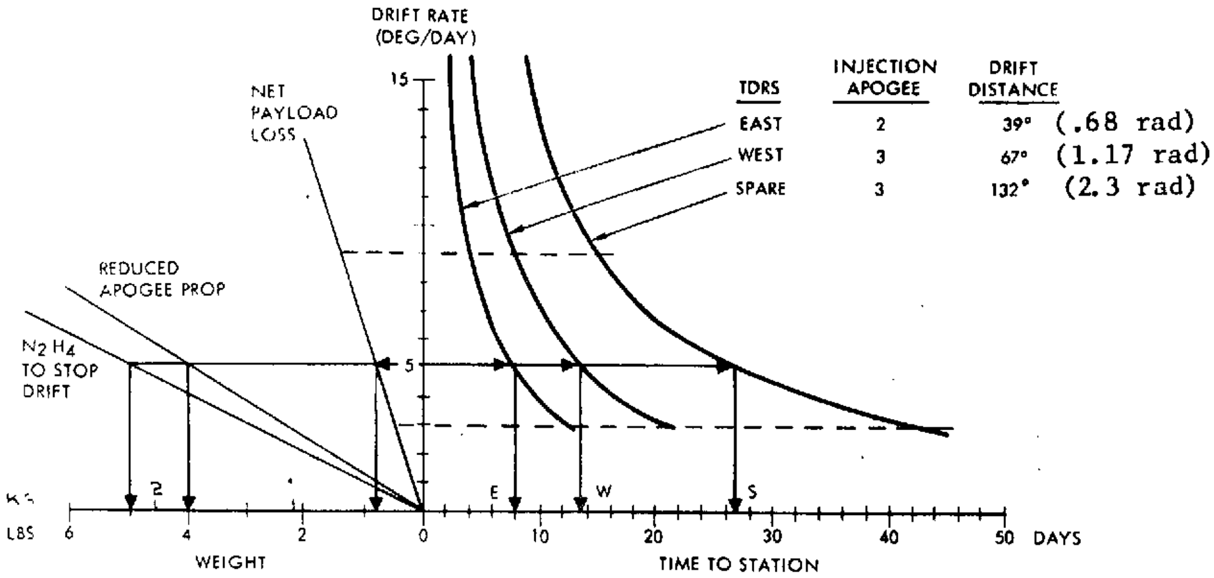


Figure 2-15. Drift Rate Effect on Payload & Drift Time

The prime criterion for the selection of the baseline TDRS drift rate is the minimum time to track and correct injection errors as they drift to station. Eight days, the time required for the east satellite, is taken as a reasonable minimum with the resulting maximum of 27 days for the spare as also satisfactory.

The east TDRS enters its drift orbit on the second apogee, 39° (.68 rad) west of its destination, with an eastward drift of 5° (.087 rad)/day. It arrives at its station in about 8 days and expends approximately 5 lb (2.3 kg) of propellant to stop the drift.

The west TDRS enters the drift orbit on the third apogee, 67° (1.17 rad) west of its destination, with the same drift rate. It arrives at its destination in 13 days and also uses 5 lb (2.3 kg) of hydrazine to stop. The spare enters its drift orbit on the third apogee, 132° (2.3 rad) west of its storage location, which is mid-way between the other two satellites. It drifts 27 days and also uses 5 lb (2.3 kg) of hydrazine to stop.

2.1.2.4 Operational Stationkeeping and Eclipse Periods

After the TDRS arrives on station, it will be subjected to north-south and east-west perturbations of its orbit. The north-south motion is due to luni-solar gravitation and changes the orbit inclination at a relatively slow rate (Figure 2-5). As discussed in Section 2.1.1.1, no orbital correction is necessary for this motion. The east-west motion, however, can cause the satellite to drift out of sight of the ground station (or move closer to it) if uncorrected for long time periods. The delta-V requirements and drift times for this phenomenon are discussed in this section.

The TDRS passes through the earth's shadow generating an eclipse period each day for several days before and after each equinox. The time per day and days per year are shown below.

<u>Stationkeeping</u>. The east-west perturbation is caused primarily by the noncircularity of the earth's equator and its magnitude depends on satellite longitudinal location. The TDRS is designed to accommodate the worst case.

There are no stringent constraints on the variation in TDRS longitudinal location. Limiting oscillations and drift to less than $\pm 1/8$ degree is adequate for this purpose and can be readily maintained.

The longitudinal drift of the familiar figure-eight ground trace of the 24-hour orbit can be described approximately by the linearized equation from Rand Report, RM 6166PR:

$$\dot{\gamma} = +(.094478 \sin 2\gamma_o)t \text{ deg/day}$$

where γ_o is the initial longitudinal displacement of the line of nodes from the 15°W meridian, and t is elapsed time in days. The rate is constant at zero when the line of nodes is initially located at a stable point and at an unstable point ($\sin 2\gamma_o = 0$). When $\sin 2\gamma_o$ does not equal zero, the nodes move toward a stable point (75°E, 105°W). The unstable points are 15°W and 165°E. 90° (1.57 rad) displaced from the stable points.

Figure 2-16 shows the initial geometry of the satellite locations and the points of stable equilibrium.

Figure 2-17 shows the distance the satellite drifts with time and the drift rate at the end of this time for the worst case position. For the selected limits of $\pm$ .125° (2.2 mrad), a total drift of .25°(4.4 mrad) is permitted. This occurs in approximately 17 days, and the drift rate is .029° (.5 mrad)/day or .27 fps (0.08 m/sec). This results in 6 fps(1.8 m/sec)/year propellant requirement. Figure 2-18 shows the effect at positions other than the maximum and the TDRS location.

<u>Eclipse Periods</u>. The angle between the orbital plane and the direction to the sun varies over the year as does the angle between the equator and the direction to the sun. When the angle is $\leq$ 10° (.175 rad), the TDRS passes through the earth's shadow for a short period each orbit. The duration of this eclipse is shown in Figure 2-19 as a function of calendar date.

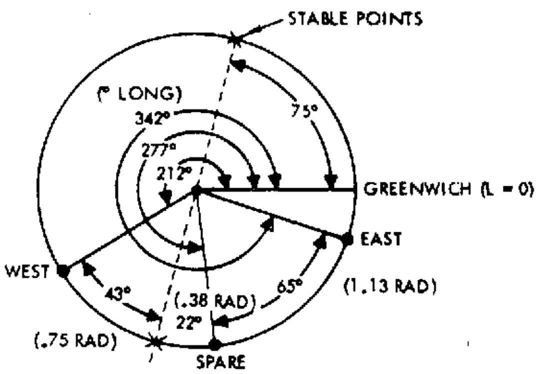


Figure 2-16. Longitudinal Location of Geosynchronous Satellites & Stable Points

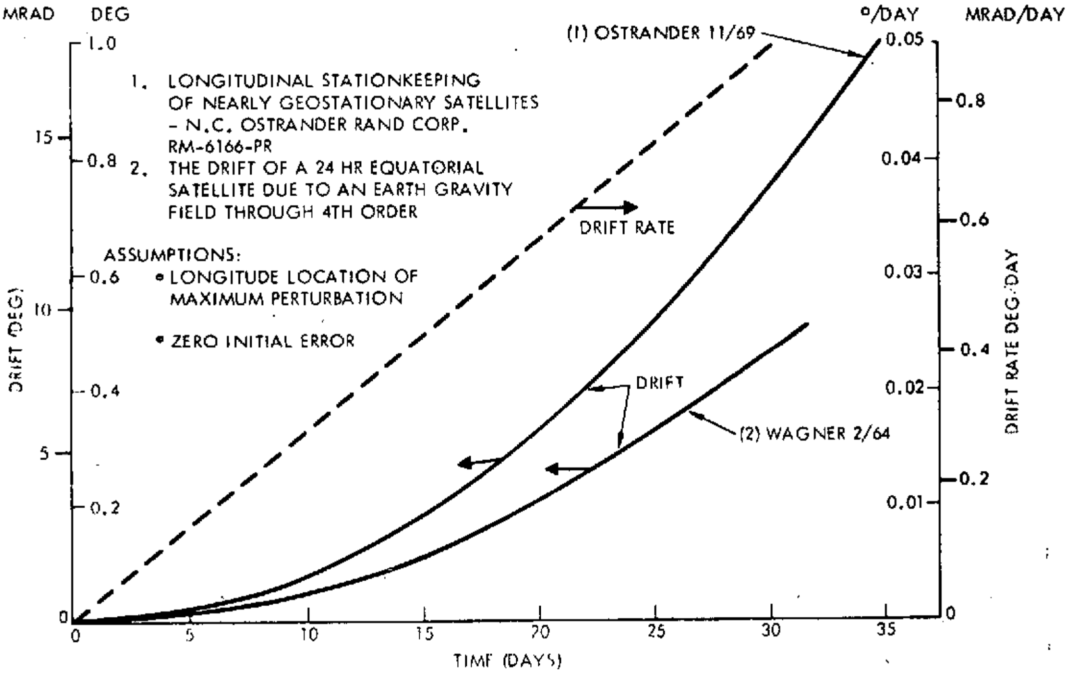


Figure 2-17. Longitudinal Drift of 24 Hr. Satellite

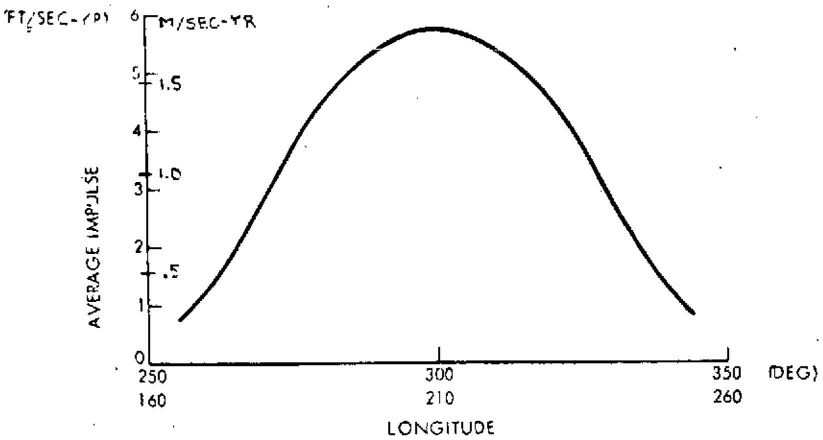


Figure 2-18. Average Annual Impulse vs Longitude

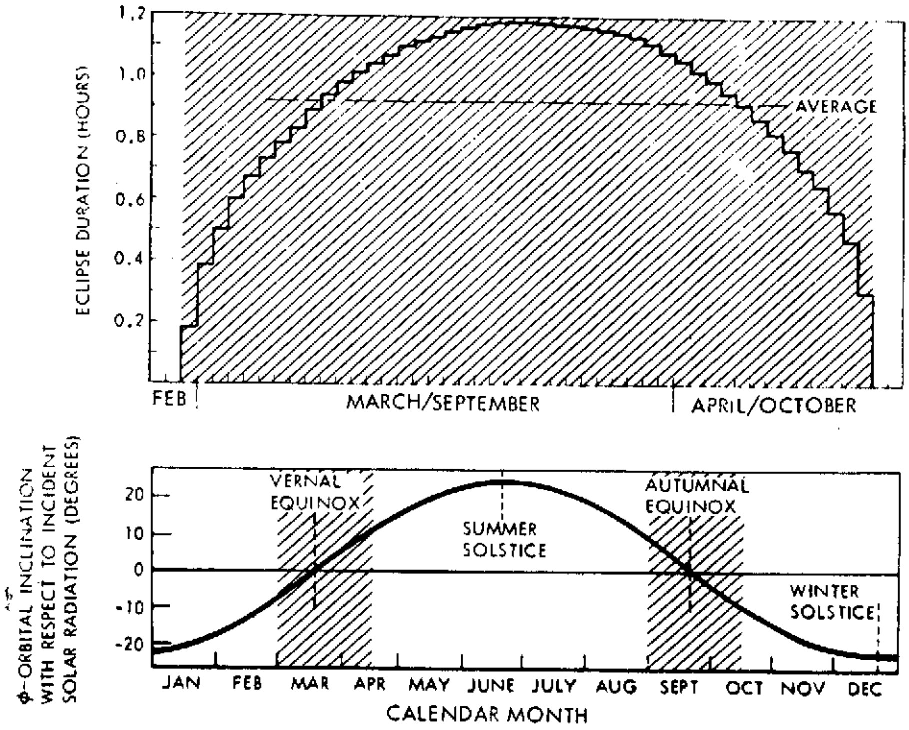


Figure 2-19. Eclipse Periods

2.1.3 Performance Sensitivity

Sensitivity coefficients can be used to assess the effect of small variations in mission and system parameters on the mission performance. Mission performance can be described in terms of various quantities such as payload weight, user visibility, and contact with the ground station. For some purposes, propellant weight and delta V are adequate indicators of mission performance.

The coefficients in Tables 2-1, 2-2, and 2-3 show the effect on mission performance of all small variations in system parameters, and the equivalent variations in the other parameters. The sensitivity coefficients in these tables are divided into three groups:

1. Orbit Characteristics. Factors affecting the motion of the TDRS with respect to the ground after arrival on station (Table 2-1).

2. Effects, on visibility of TDRS and user, of varying inclination to change payload capability (Table 2-2).

3. Effect of varying apogee motor performance and design characteristics on payload, propellant, and initial gross weight (Table 2-3).

Table 2-1. Sensitivity Related to Orbital Maneuvers

Sensitivity of → / To Unit Change in ↓		Velocity V fps (m/sec)	Average Orbit Radius a n.m. (KM)	Eccentricity e	Orbital Period P HRS	Drift Rate θ deg per rev.	Maneuver Propellant Wp lb (KG)
Velocity *	fps (m/sec)	1 (1)	4.5 (6.07)	9.9×10^{-5} (3.25×10^{-4})	.00711 (.0233)	.1062 (.3484)	.0979 (1.489)
Average Orbit Radius	n.m. (KM)	.222 (0.1647)	1 (1)	2.2×10^{-5} (4.07×10^{-5})	.00158 (.00293)	.0236 (.0437)	.02175 (.00533)
Eccentricity		10101×10^{5} ($.30808 \times 10^{4}$)	$.454 \times 10^{5}$ ($.841 \times 10^{5}$)	1	71.7	1070.	986.0 (447.6)
Orbital Period	hrs	140.65 (42.90)	633.0 (1172)	.01395	1	14.933	13.73 (6.23)
Drift Date	deg. per rev.	9.416 (2.87)	42.1 (78.0)	9.34×10^{-4}	.0669	1	.921 (.418)
Maneuver Propellant	lb. (KG)	10.21 (6.87)	46.1 (188)	.00101 (.00223)	.0728 (.1605)	1.086 (2.381)	1 (1)

*One Impulse or Intermediate Circular Orbit

Table 2-2. Sensitivities Related to Inclination

Sensitivity of → / To Unit Change in ↓		T.O. Incl. Deg.	Final Incl. Deg.	TDRS Spacing Deg.	Visible Altitude n.m. (KM)	Payload lb. (KG)	Apogee Propellant lb. (KG)
T.O. Inclination	Deg.	1	.547	-.818	-18.20 (-33.71)	3.0 (1.36)	13.0 (5.9)
Final Inclination	Deg.	1.83	1	-1.5	-33.4 (-61.86)	5.5 (2.50)	-5.0 (2.27)
Spacing	Deg.	-1.222	-.666	1	22.31 (-41.32)	-3.67 (-1.67)	3.33 (1.51)
Visible Altitude	n.m. (KM)	-.0161 (-.00869)	-.0088 (-.0048)	.0131 (.00707)	1 (1)	-.1645 (-.0403)	.1498 (.0367)
Payload	lb. (KG)	.333 (0.734)	.182 (.401)	-.2725 (-.6006)	-6.08 (-24.83)	1 (1)	-.909 (-.909)
Apogee Propellant	lb. (KG)	.0769 (.169)	-.2 (-.441)	.300 (.661)	6.68 (27.28)	-1.1 (-1.1)	1 (1)
Min. Elev. Angle at Ground Station	Deg.	NA	NA	2	82.6 (153)	NA	NA

The sensitivity coefficients were developed from three types: the slope of a tradeoff curve; a perturbed computer solution; and a partial derivative of a closed form analytic expression.

Table 2-3. Sensitivity to Apogee Motor Parameters

Sensitivity of → / To Unit Change in ↓	Initial Gross Wt. lb (KG)	Propellant Weight lb (KG)	Payload Weight lb (KG)
Initial Gross Wt(lb)or(KG)	1	.4661	.5339
Propellant Wt.(lb) or (KG)	2.145	1	1.145
Payload Wt. (lb) or (KG)	1.873	.873	1
Inert Wt. (lb) or (KG)	-1.873	-.873	-1
Attach Fitting Wt(lb)or(KG)	-1	-.4661	-.5339
I_{SP}(SEC)	0 (0)	- 1.733 (0.787)	1.733 (0.787)
V (FPS) (M/sec)	0 (0)	-.0859 (-.128)	-.0859 (-.128)
Drift Rate $\dot{\phi}$ (^{0}/REV.)	.008 (.0036)	-.745 (-.338)	.753 (.342)

2.1.4 TDRS On-Orbit Payload Capability

The previous sections defined the capability of the Delta 2914/TE-M-616 apogee motor to synchronous orbit. The increase in payload and reduction in required apogee motor propellant due to the "drift bias" injection mode was discussed. An additional factor that must be considered in establishing the on-orbit payload is the further reduction in apogee motor propellant due to on-board propellant consumed during transfer orbit that need not be injected into synchronous orbit. This reduction in apogee propellant can be partially converted into payload.

The Delta 2914 injects 1490 lb (677 kg) into a 27° (.47 rad) inclination orbit. transfer orbit. Six pounds (2.7 kg) of propellant are used for precession and nutation damping during transfer, leaving 1484 pounds (675 kg) at synchronous orbit injection.

This requires 1484 (.4661) = 692 lb (314 kg) of propellant (Table 2-3) and 1484 - 692 = 792 lb (360 kg) of payload. Included in the payload is 50 lb (22.7 kg) of empty motor case and 8 lb (3.6 kg) of burned-out insulation. The resulting 734 lb (333 kg) of useful payload is injected into synchronous orbit.

However, the "drift bias" mode allows a reduction in apogee propellant of .745 lb/deg (.338 kg/deg) x 5°(.087 rad)/day = 4 lb(1.8 kg)(Table 2-3), and an increase payload of .753 x 5 = 4 lb (1.8 kg).

This results in the following propellant and payload values into the 5-degree/day drift-bias orbit.

Payload = 734 + 4 = 738 lb (335 kg)
Apogee propellant = 692 - 4 = 688 lb (313.4 kg)

2.1.5 Launch and Deployment Profile

Based on the TDRS operational philosophy discussed in Section 2.1.2, a baseline flight profile was established in which the TDRS is injected into the transfer orbit at the first descending node of the parking orbit. Each operational satellite is injected at the apogee most convenient for eastward drift to its station. Locations of the first three apogees in such case are at 104 degrees, 306 degrees, and 148 degrees longitude, respectively. Minimum reliance is placed on launch vehicle reliability while having minimum effect on the spacecraft reliability. Nearly continuous visibility of the spacecraft is maintained during launch and deployment into orbit for initial tracking orbit determination and adjustment by use of the STDN tracking stations at Tananarive, Orroral, Rosman and Guam. Only 118 minutes of tracking time visibility is lost at the second perigee and 38 minutes at the third perigee, both of which are not considered serious.

The spacecraft and launch vehicle are injected into a low(100 nm(185KM) circular inclined orbit and at the first descending node the spacecraft is injected into a Hohmann ellipse having a perigee equal to the circular orbit and an apogee at synchronous altitude. At some apogee passage (second or third) of the transfer orbit the spacecraft is injected into a near-circular equatorial orbit, i.e., the thrust simultaneously removes the eccentricity and inclination of the transfer orbit, leaving slight residuals resulting from non-perfect systems performance. These residuals are removed by a vernier propulsion correction system.

Figure 2-20 illustrates the total mission profile for launch and deployment into operational status. The total mission is divided into three phases: (1) boost, (2) transfer orbit, and (3) preoperational synchronous orbit phase. These are discussed below. The operational phase is discussed in Section 2.2.

2.1.5.1 Boost Phase Profile

Each TDRS is launch from ETR by a Delta 2914 with a TE-364-4 third-stage at a launch azimuth of 90 degrees. Figure 2-21 shows the boost profile, from liftoff through third-stage burnout and separation, with significant events and associated times from liftoff. The vehicle lifts into a parking orbit at a nominal altitude of 100 nm (185 KM) with an inclination of approximately 28.3°(.5 rad). The fairing is jettisoned about 36 seconds after Stage II ignition and 4 minutes before the first Stage II cutoff command and start of the parking orbit coast phase. Coast lasts 16.22 minutes and concludes when the vehicle reaches the first descending node (first perigee) at 3 degrees

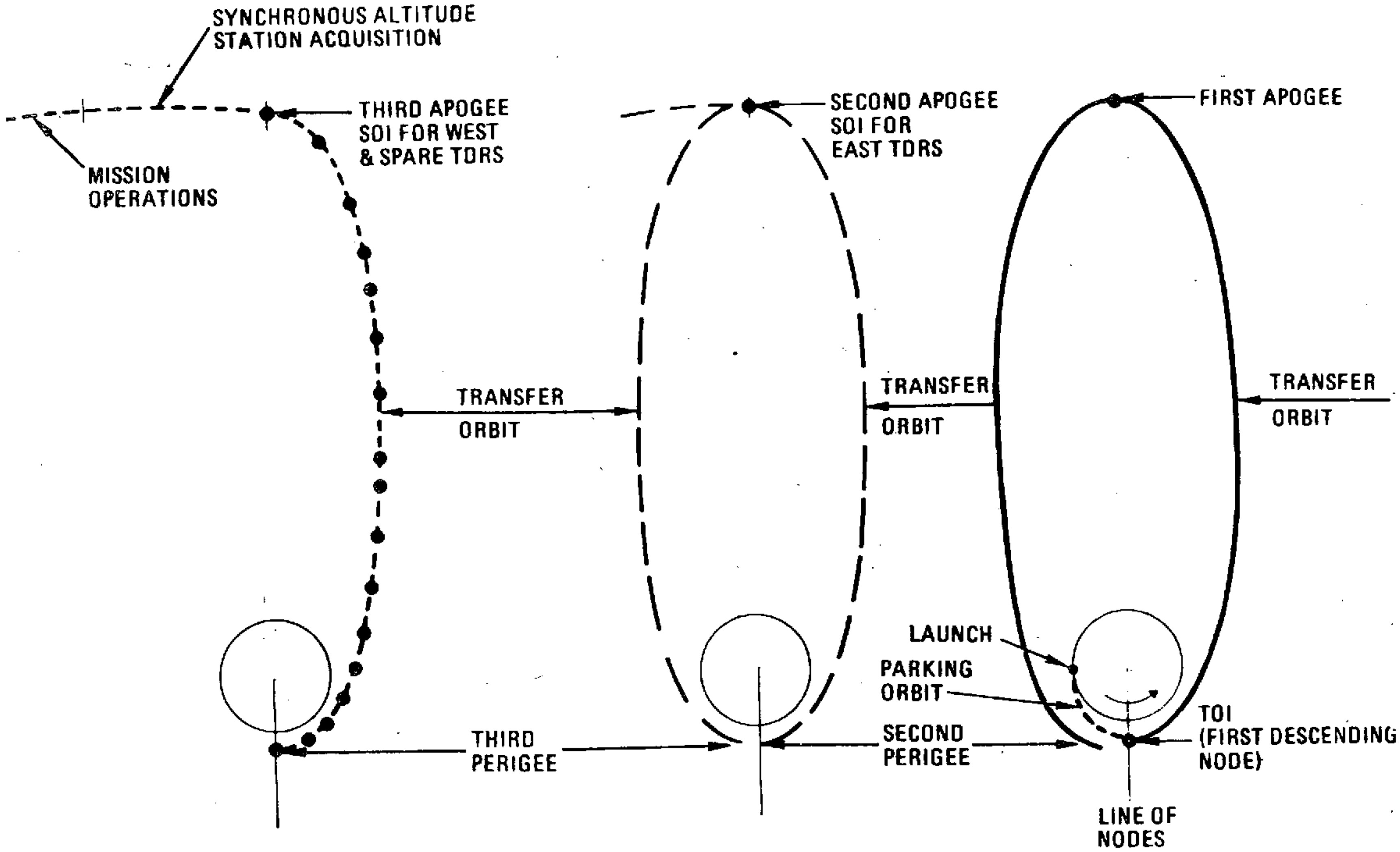


Figure 2-20. Overall Launch and Deployment Profile

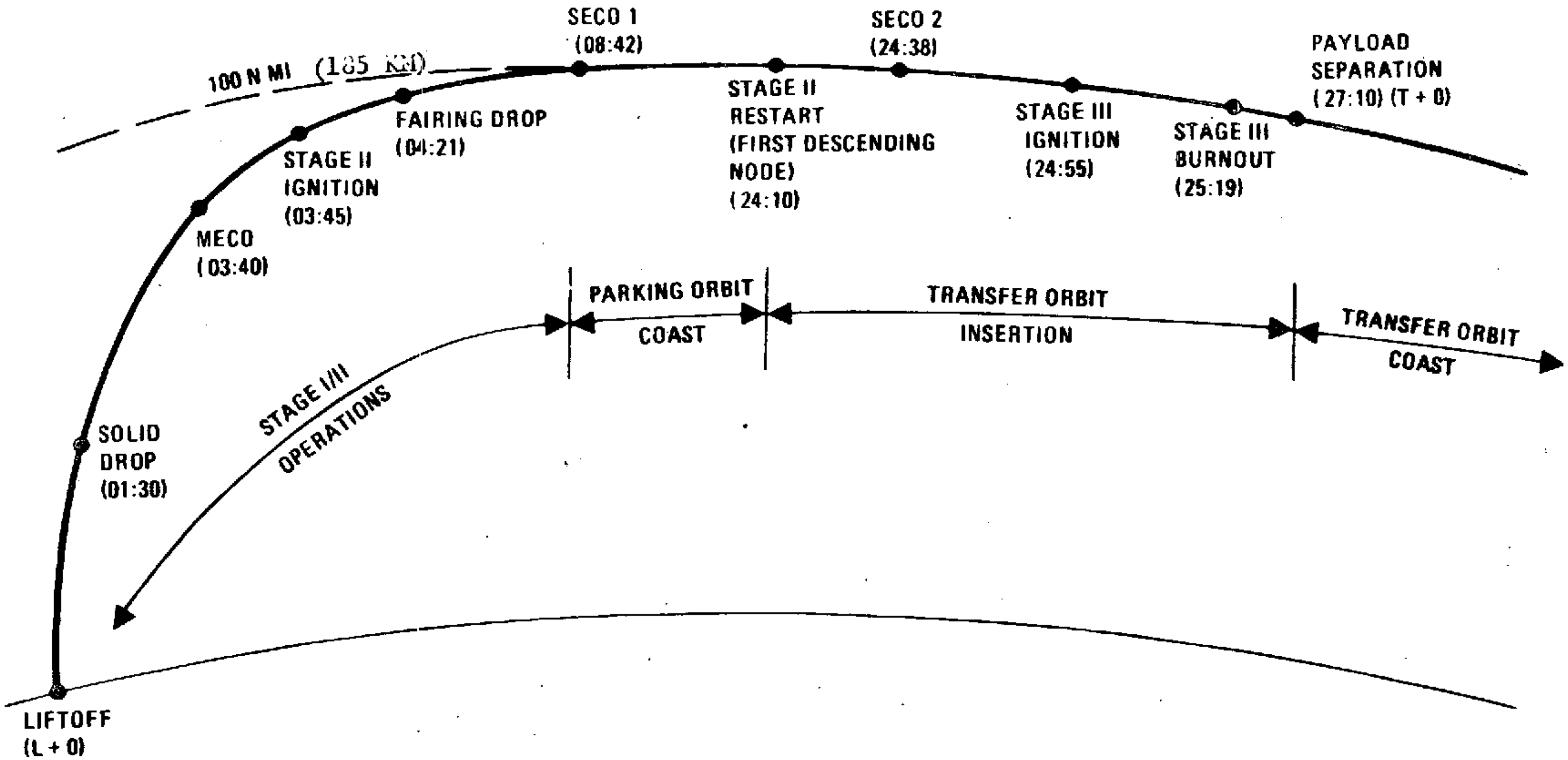


Figure 2-21. Boost Phase Profile

east longitude. At the node, the second stage restarts and uses its residual energy to inject into the transfer orbit. The second burn of Stage II lasts 28 seconds. After its burnout, the third stage and the TDRS are spun up to 90 rpm, Stage III ignites and burns for 24 seconds to complete transfer orbit insertion. Payload separation occurs two minutes after Stage III burnout, 27 minutes after liftoff and 3 minutes after first descending node injection. The TDRS remains spinning until after insertion into synchronous orbit.

2.1.5.2 Transfer Orbit Phase Profile

At the first descending node the vehicle is injected into a 27° (.47 rad) inclination transfer orbit by the solid propellant Delta 2914 third stage which changes the inclination from that of the parking orbit to that of the transfer orbit. After payload separation (~110 nm (204 KM) the spacecraft coasts to synchronous altitude in an elliptical 180° (3.14 rad) transfer orbit which combines simplicity of implementation and economy of propellant and has been used successfully in other space missions. The long transit allows time for smoothing and processing of tracking data and for reorienting the spacecraft for the apogee motor burn. The transfer orbit profile is shown in Figure 2-22 with a transfer time from injection (perigee) to apogee (one-half orbit) of 5.25 hours.

During the entire transfer orbit, the spacecraft will be spinning and will maneuver into appropriate attitudes for attitude determination and measurement, and nutation will be damped out. These operations continue as required through the entire transfer orbit. Precession operations include those near the start of the transfer orbit plane (appropriate for earth scanning and attitude measurements) and those nearer the apogee which precess the spin axis to synchronous orbit insertion attitude.

In this transfer time the spacecraft must also acquire the sun, establish contact with the ground stations and reorient for apogee maneuver. For example, the spacecraft comes into view of the STDN Tananarive tracking station about 6 minutes after transfer orbit injection (first descending node), Orroral about 29 minutes after node injection, and Rosman about 12 hours after node injection.

The initiation of the vehicle reorientation maneuvers occurs within the first half hour after transfer orbit injection and the spacecraft has come into view of the ground station, so that all systems can be activated and checked out and the reorientation commands given from the ground. The torque vector is applied along an axis normal to the major axis of the transfer orbit, normal to the spin vector, in the plane of the desired precession so that the vehicle is precessed about the major axis of the transfer ellipse (line of nodes). Since the spacecraft is spinning at a rate imparted by the launch vehicle, it is reoriented by means of periodic synchronized precessional torque impulses. The sequence of operations for accomplishing this is illustrated in the figure and at least one and one-half orbits (15.75 hours) are provided to obtain data and make the necessary corrections prior to synchronous orbit insertion.

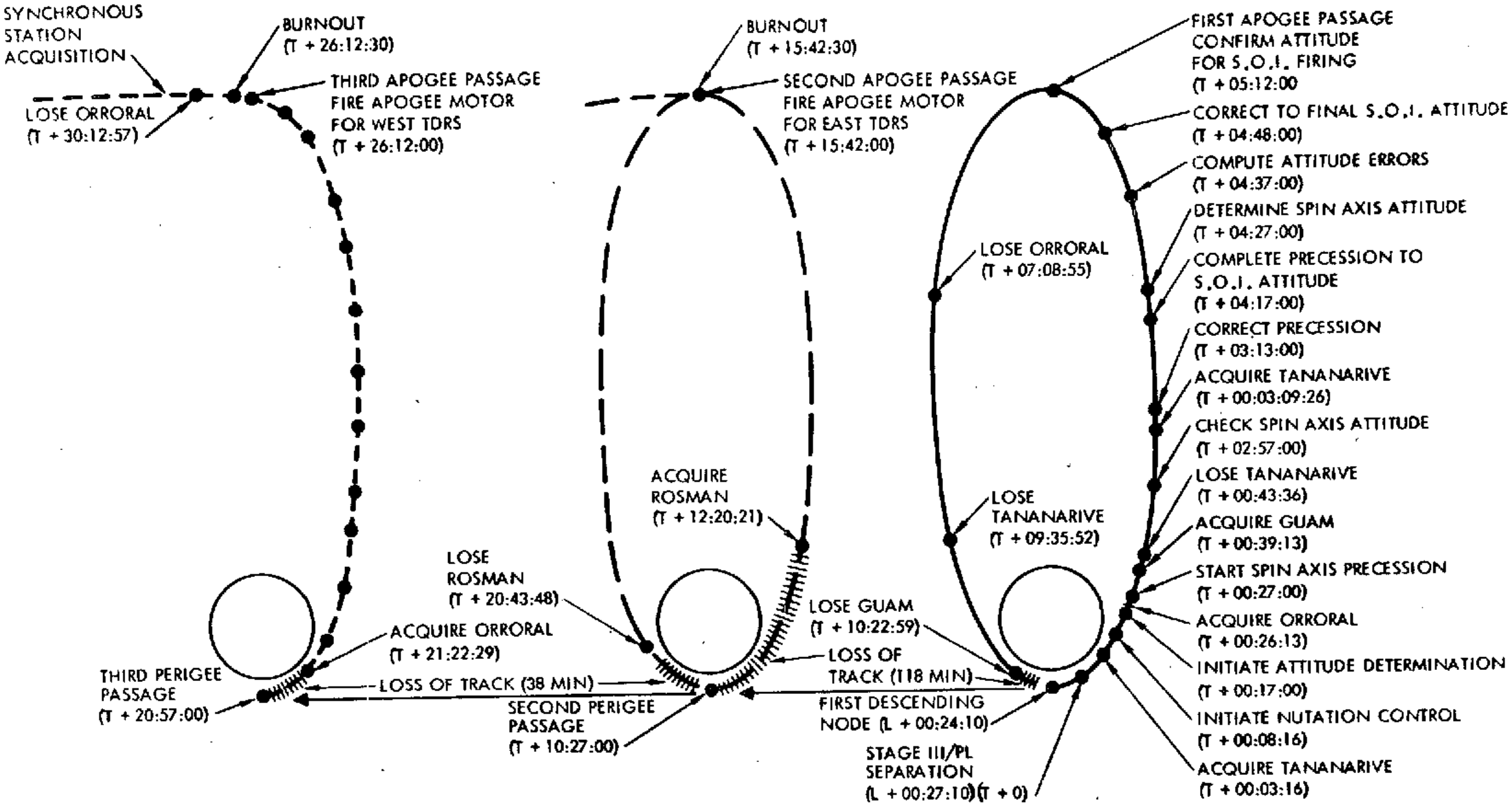


Figure 2-22. Transfer Orbit Phase Profile

For proper deployment of the spacecraft into the desired longitude location, the east spacecraft is inserted into the synchronous altitude at the second apogee and the west and spare satellites at the third apogee. At the given apogee, the apogee motor fires to change plane and circularize the orbit at synchronous altitude for approach to operational station. This deployment philosophy provides a complete transfer orbit time of approximately 15.75 hours to the second apogee and approximately 26.25 hours to the third apogee, sufficient for all required operations and economic fuel consumption.

2.1.5.3 Preoperational Synchronous Orbit Phase Profile

After apogee motor burnout, the spacecraft is despun and stabilized (momentum wheels spun) in an essentially equatorial orbit (Figure 2-23). The solar panels are deployed 1.5 hours after spacecraft despin and the antennas are deployed about 20 minutes later. The spacecraft then acquires the sun and earth and achieves near-continuous sunlight for the mission at synchronous altitude. The spacecraft drifts to its assigned station. Appropriate post-apogee delta-V maneuvers are performed to correct the spacecraft injection errors and to acquire the proper drift orbit (about 24 hours after apogee motor burnout).

2.1.6 Launch and Deployment Timeline

Table 2-4 presents a timeline for the Delta 2914/TDRS launch and deployment phases of the mission showing the sequence of the major events, associated functions, the equipment, process or agency initiating the event, and the time from liftoff at which the event takes place. This timeline is for the case of insertion into the transfer orbit at the first descending node and synchronous orbit insertion at the second or third apogee. The timeline is given for three phases of the total pre-operational mission: launch phase, transfer orbit phase, and pre-operational synchronous orbit phase. The events in each phase are identified by a phase-identified sequence of times. The timeline is developed through the operations required to achieve operational status.

The acquisition and loss-of-track times by a number of tracking stations during the course of the flight to operational mission status are included in the timeline. The tracking stations which may participate during this flight are Tananarive (Madagascar), Orroral (Australia), Guam, and Rosman (North Carolina). The times of passage through each perigee and apogee up to apogee motor firing and insertion into the synchronous orbit are also included.

The timeline shows an appropriate sequence of events to fit the TDRS phasing philosophy. It shows dependency of one event upon another; it allocates suitable time expenditures to each event; and it permits inference of alternate operations and events.

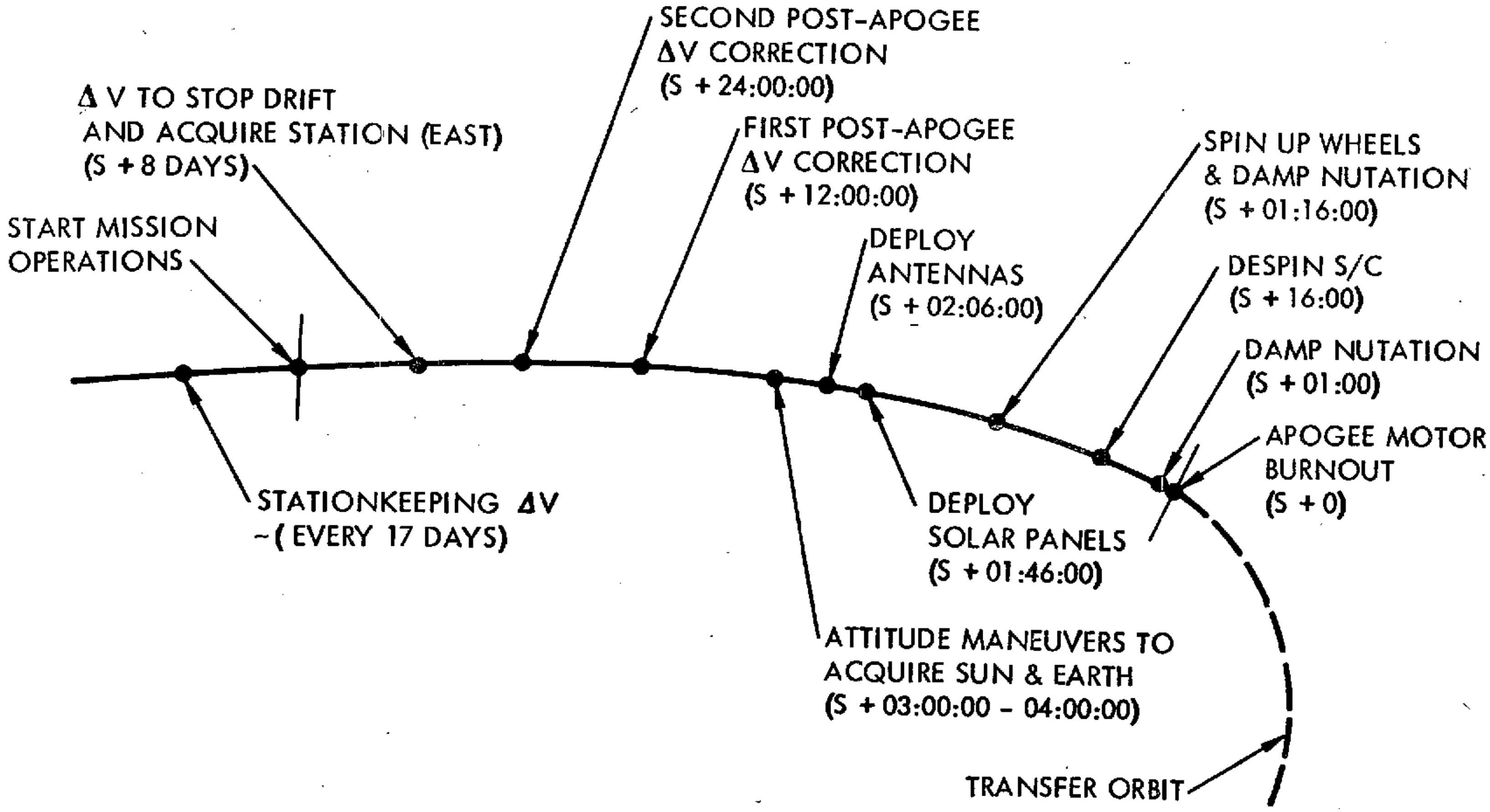


Figure 2-23. Pre-Operational Synchronous Orbit Phase Profile

Table 2-4. Delta 2914/ TDRS Launch and Deployment Timeline

Time	Event	Function	Initiated By
	A. LAUNCH PHASE		
L+00:00:00	Liftoff		
L+00:00:02	Initiate first stage open-loop guidance		
L+00:01:30	Solid motor separation		
L+00:01:42	Initiate Stage I closed loop guidance		
L+00:03:40.5	Main Engine Cutoff (MECO) - Stage I burnout		
L+00:03:44.5	Blow Stage II/I sep. bolts		
L+00:03:45	Start Stage II engine		
L+00:03:46	Transfer guidance control to Stage II		
L+00:03:48	Initiate Stage II open-loop guidance		
L+00:04:21.5	Jettison payload fairing Initiate tracking	Expose spacecraft and Stage III tracking	Ground (tracking) station
L+00:08:42.5	Stage II engine cutoff command No. 1; initiate ground TM link and house-keeping operations	Achieve parking orbit communications	
L+00:10:20.5	Initiate Stage II coast No. 1 guidance		
L+00:23:30.5	Restart conditioning Turn on hydraulic pump Initiate ullage jets		
L+00:24:10.5	Engine restart	Transfer orbit injection (first descending node)	
L+00:24:38.5	Stage II engine cutoff command No. 2		
L+00:24:40.5	Fire spin rockets	Vehicle stabilization	
L+00:24.41	Start Stage III sequence timer		
L+00:24:41.5	Fire Stage III ignition wire cutters		
L+00:24:42.5	Blow Stage II/III separation bolts; fire Stage II retros		
L+00:24:55.5	Stage III ignition		
L+00:25:19.5	Stage III burnout		Depletion
L+00:27:10.5 (T+0)	Payload/Stage III separation		

Table 2-4. Delta 2914/TDRS Launch and Deployment Timeline (Cont)

Time	Event	Function	Initiated By
B. TRANSFER ORBIT PHASE			
T+0	Payload/Stage III separation		
T+00:00:47.5	Continue tracking, TM and housekeeping operations	Tracking, communications, housekeeping	Tracking station antenna (ascension or ship)
T+00:03:16	Acquire spacecraft by TANANARIVE	Tracking	Tracking station antenna
T+00:08:16	Initiate and continue active nutation control as required through spacecraft despin	Damping spacecraft wobble	G.S. command enables ANC mode
T+00:17:00	Initiate attitude determination and continue	Definition of spin axis orientation	TDRS control center and G.S.
T+00:26:13	Acquire spacecraft by ORRORAL	Tracking	Tracking station antenna
T+00:27:00	Initiate spin axis reorientation maneuver to S.O.I attitude	Precession of spin vector about Line of Apsides	G.S. command
T+00:39:13	Acquire spacecraft by GUAM	Tracking	Tracking station antenna
T+00:43:36	Lose spacecraft track by TANANARIVE	Tracking	Tracking station antenna
T+02:57:00	Confirm spin axis attitude	Checking attitude as spin vector becomes normal to orbit plane	TDRS control center and G.S.
T+03:09:26	Acquire spacecraft by TANANARIVE	Tracking	Tracking station antenna
T+03:13:00	Correct spin axis precession as required		G.S. commands
T+04:17:00	Complete spin axis reorientation to approximate S.O.I. attitude		G.S. command
T+04:27:00	Determine spin axis attitude	Continue attitude determination	TDRS control center and G.S.
T+04:37:00	Compute spin axis attitude errors	Adjustments to attitude	TDRS control center and G.S.
T+04:48:00	Precess to correct spin axis attitude to final S.O.I. attitude	Spin axis attitude corrected during approach to apogee passage	TDRS control center and G.S. command
T+05:12:00	Pass through first apogee Confirm spin axis attitude for S.O.I. firing	Assure attitude correct for S.O.I. firing	TDRS control center
T+07:08:55	Lose spacecraft track by ORRORAL	Tracking	Tracking station antenna
T+09:35:52	Lose spacecraft track by TANANARIVE	Tracking	Tracking station antenna
T+10:22:59 1	Lose S/C track by GUAM	Tracking	"
T+10:27:00	Pass through second perigee		
T+12:30:21	Acquire S/C by ROSMAN	Tracking	Tracking station antenna

Table 2-4. Delta 2914/TDRS Launch and Deployment Timeline (Cont)

Time	Event	Function	Initiated By
	B. TRANSFER ORBIT PHASE		
T+15:42:00 ②	Pass through second apogee Apogee motor firing for east TDRS		G.S. command
T+15:42:30.5 ② (S+0)	Apogee motor burnout	Apogee motor injects to eastward moving drift orbit	G.S. command
T+20:43:48 ③ ④	Lose track by ROSMAN	Tracking	Tracking sta. antenna
T+20:57:00 ③ ④	Pass through third perigee		
T+21:22:29 ③ ④	Acquire S/C by ORRORAL	Tracking	Tracking sta. antenna
T+26:12:00 ③	Pass through third apogee Apogee motor firing for west TDRS and spare		G.S. command
T+26:12:30.5 ③ (S+0)	Apogee motor burnout	Apogee motor injects to eastward moving drift orbit	G.S. command
	C. PREOPERATIONAL SYNCHRONOUS ORBIT PHASE		
S+0	Apogee motor burnout		Depletion
S+0:01:00	Damp nutation	Damp spacecraft wobble	G.S. command
S+00:16:00	Despin S/C, repetitively command jet torques as function of sun sensor outputs to reduce spin rate	Command jet torques	G.S. command
S+01:16:00	Spin up momentum wheels and damp nutation (reaction jets inhibited)	Stabilize spacecraft about 3 axes	G.S. command
S+01:46:00	Release and deploy solar panels		G.S. command
S+02:06:00	Release and deploy antennas		G.S. command
S+03:00:00	Perform pitch and roll attitude maneuvers in that order to acquire sun attitude reference	Acquire sun reference	G.S. command
S+04:00:00	Perform pitch and roll scan maneuvers to acquire horizon	Acquire earth with horizon sensor	G.S. command
S+04:32:26.5	Lose track by ORRORAL	Tracking	Tracking sta. antenna
S+12:00:00	Perform first post-apogee delta-V correction maneuver	Sequence of at least two delta-V maneuvers to correct orbit injection errors	G.S. command
S+24:00:00	Perform second post-apogee delta-V correction maneuver	Acquire corrected drift orbit	G.S. command
S+~8 days ⑤	Perform delta-V maneuvers to stop longitude drift at station (east TDRS)	Transfer from drift orbit to synchronous orbit at operating station	G.S. command

Table 2-4. Delta 2914/TDRS Launch and Deployment Timeline (Cont)

Time	Event	Function	Initiated By
C. PREOPERATIONAL SYNCHRONOUS ORBIT PHASE			
S+ 12:04:00:00	Initiate attitude maneuvering for attitude determination, sensor calibration and bias estimation	Small attitude deviations to "MAP" and calibrate sensor outputs	G.S. command
S+12:06:00:00	Initiate antenna boresight bias estimation	Improve antenna beam pointing accuracy	TDRS control center and G.S. command
S+~13 days	Initiate mission operations	Mission operations	G.S. command
S+~16 days	Perform E-W stationkeeping delta-V maneuvers (as required, approximately every 17 days)	Correct orbit for perturbation effects of solar/lunar forces	G.S. command

NOTES

① Loss of tracking - 118 minutes

② These operations are for the east TDRS No. 3 synchronous orbit injection on second apogee

③ These operations are for the west TDRS No. 1 synchronous orbit injection on third apogee

④ Loss of tracking - 38 minutes

⑤ For west TDRS this becomes S + ~13 days
For spare TDRS this becomes S + ~21 days
Subsequent times will change by equivalent amounts

2.2 NETWORK OPERATIONS AND CONTROL

This section describes the operations and control of the TDRSS network. This consists of:

a. Development and description of a TDRS System Concept.

b. Description of the operational interfaces and functional relationships between primary TDRS system elements for network operations.

c. Functional analysis of TDRSS operations from which functional flow diagrams are developed to a third/fourth level of operations.

d. Tabulation and description of the sequence of events involved in a representative operational phase mission of two operational TDRS spacecraft providing service to LDR and MDR User Spacecraft.

Primary emphasis in these studies of network operations and control is given to achieving real-time system operations. However, consideration is also given to the use of existing and planned facilities and organizations to the maximum possible extent for cost-effective operation.

2.2.1 TDRS System Concept

Figure 2-24 illustrates a TDRS System Concept which can function in a real-time mode to operate and control the TDRSS Network. The figure shows three groups of elements: A GSFC-located group of ground elements, a remote-located group of ground elements, and a space group.

The space group consists of the two operational TDRS spacecraft at geosynchronous altitude with two-way communications links to the RF Ground Station, and the population of low data rate and medium data rate User spacecraft at low earth orbit, including the Space Shuttle. The East and West TDRS spacecraft are separated by 130° (2.26 rad) to provide almost complete coverage of the population of earth orbiting User spacecraft. Not shown is a third TDRS spacecraft midway between the East and West spacecraft as an orbital spare for replacement of either operational TDRS spacecraft.

The Ground System must be designed and operated to provide and maintain realtime communications between all elements to make maximum utilization of the benefits inherent in a ground-supported space relay system. However, practical constraints require maximum possible use of existing and planned facilities and organizations for cost-effective operation and efficient implementation of the system. These basic requirements imply as much reduction of long land lines as possible since these are both costly and complex. They also imply that the existing roles and responsibilities of the Users in controlling their own spacecraft must be preserved. This is especially true for the large Users who have had this responsibility and will continue to exercise it. For appropriate use of real time communications, and control, the TDRS ground network must assure these large Users a real-time capability to control their own spacecraft even when integrated into a total TDRS System.

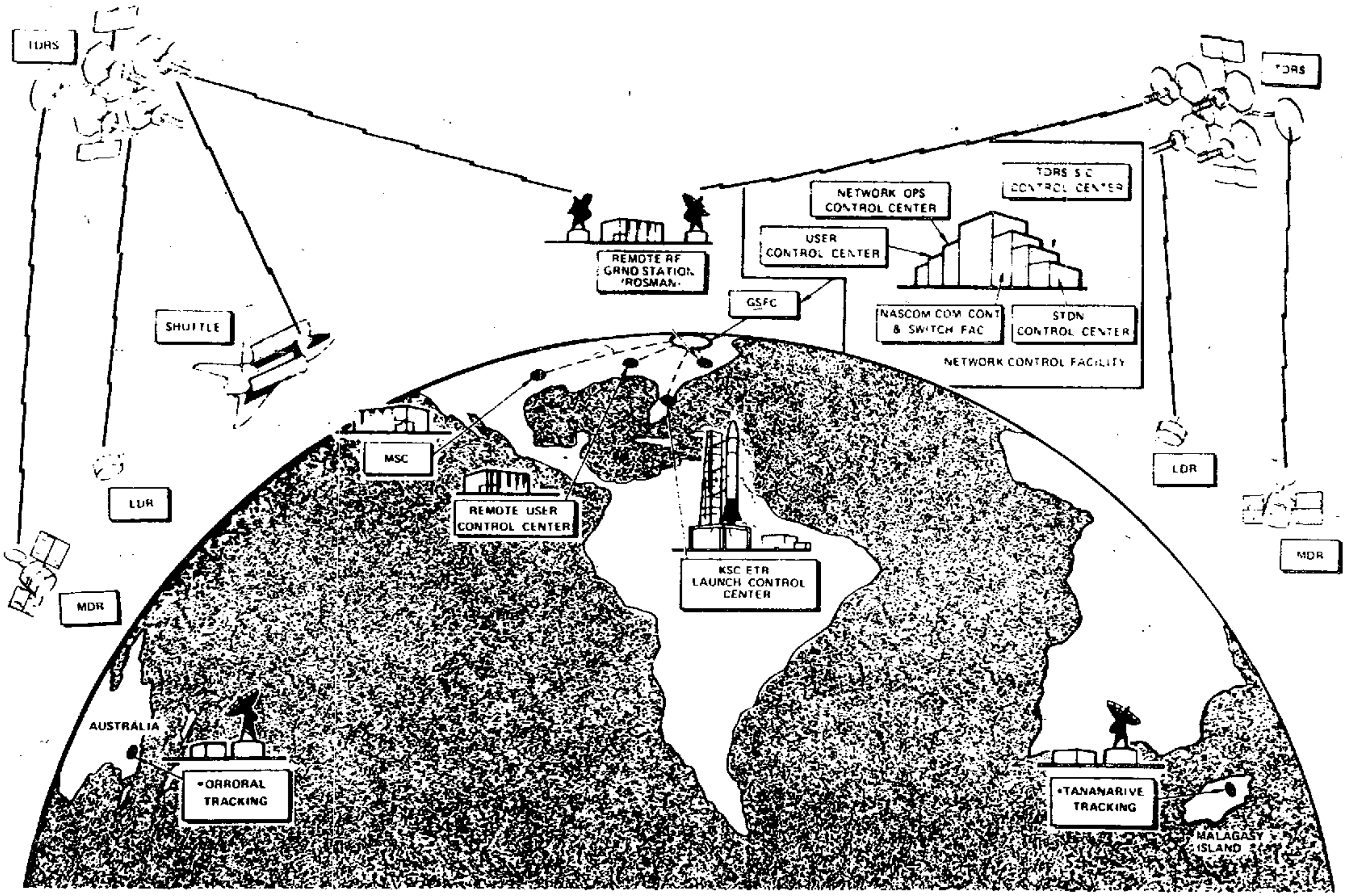


Figure 2-24. TDRS System Concept

An individual operating center is generally not required to satisfy the service requests of small users. These can be handled routinely by mailing or telephoning these requests to an operating center elsewhere in the network. This philosophy minimizes the need for development of new facilities for the TDRS Network without sacrificing real-time communications and relay service while achieving cost-effective implementation and operation.

The Ground System will have two important groups of elements: A GSFC-located group and a remote-located group. The TDRS RF Ground Station is shown at Rosman, North Carolina, although it could be placed at any other desired location; this one at Rosman keeps the land lines to GSFC at a minimum. The RF Ground Station houses the antennas for direct interface with the TDRS. Since these antennas to the TDRS will be large [60 ft (18.3 m) antennas] the RF Ground Station will also be a large facility and will very likely be remotely located away from GSFC. Other elements remotely located away from GSFC are the Manned Spacecraft Center at Houston, some User Control Centers throughout the country, the Launch Control Center at the Eastern Test Range, and STDN Tracking Stations.

All the remote elements will be linked by communications lines to the control centers at the Network Control Facility at GSFC. The Manned Spacecraft Center controls the manned spacecraft including Space Shuttle which is expected to be an important TDRS User. The remote User Control Centers control various project mission spacecraft, control of which has been and will continue to be in these remote locations. ETR will be the launching site for TDRS and will be linked to the TDRS Spacecraft Control Center at GSFC by long land lines, video and voice links to achieve real-time control and communications during the launch phase. STADAN and MSFN ground stations are being consolidated into an integrated STDN system.

Two tracking stations of the consolidated STDN Network are shown at Orroral, Australia and at Tananarive, Malagasy Island; these, in addition to tracking facilities at Rosman and Guam, will track the Delta 2914/TDRS vehicle from launch through the boost, transfer orbit and pre-operational synchronous orbit phases of the mission up to deployment into the designated operational station. The use of another TDRS RF Ground Station location rather than at Rosman or in addition to Rosman is still presently open as an option. The use of more than one station achieves station diversity and the separation and multiplication of antennas.

The Network Control Facility is shown located at GSFC. It is a centralized operating organization with hard line communications links connecting the internal elements of the group. The operational concept is not basically altered by locating this facility elsewhere than at GSFC, except for increasing the length, complexity and cost of the communications lines. The many User Control Centers presently located at GSFC and the substantial facilities already in the GSFC complex suitable for TDRSS operation make it cost-effective to place this facility at GSFC. The GSFC-located elements contain a number of primary ground elements whose interfaces and functions are described in detail in Section 2.2.2. These elements are organized and operated to achieve real-time communications and control. The elements in this facility include: (a) a Network Operations Control Center (NOCC) to interconnect and control the network elements; (b) a TDRS Spacecraft Control Center (TDRSCON) to control the TDRS spacecraft; (c) a number of User Control Centers to control the various User spacecraft; (d) a NASCOM Communications Control and Switching Facility to handle, switch and direct the flow of communications between the various elements internal to the Network Control Facility as well as externally to remotely located elements; (e) a STDN Control Center is shown for centrally directing and monitoring the supportive functions of the STDN group of ground stations.

The large Users at GSFC will undoubtedly have an operations control unit to effectively manage their real-time service requirements, allowing them to proceed directly through a Network Control Facility communications processor for command multiplexing and priority routing to a data encoder and high speed modem and thence on to the RF Ground Station. The Network Control Facility will provide the necessary status, orbit data and scheduling to permit timely and effective entry into the operating schedule. More routine operations can proceed by other than such real-time means, as would service requirements of some small Users not having operations control units of their own and not real-time sensitive.

Many specific features of the TDRS System, such as facilities, locations and responsibilities, are still subject to continuing study of various options. However, the basic requirement remains to implement functions and operations that achieve simultaneous, real-time, effective relay service to the Users. The illustrated system concept serves as a tool to establish the functional and operational requirements, to define the roles and responsibilities of the elements involved, and to define the functions and operations that meet these objectives. The operational interfaces and relationships between all the primary elements of such a system concept and the functional and operational analyses of the services provided by each element of the system are given in the following sections. They are defined to meet the objectives of real-time operation with minimum impact on existing or planned organizations and responsibilities.

2.2.2 Primary System Elements and Their Operational and Functional Interfaces

The TDRSS must be designed in concert with the user spacecraft systems, the ground systems, the user mission control systems, and all the supporting data management systems. Minimum impact, especially in the initial periods of operation, should be exerted upon the interfacing systems.

Use of a TDRS to command, control, and relay data from a user spacecraft can contribute materially to simpler user spacecraft designs, higher autonomous capabilities, and simpler ground systems with more comprehensive spacecraft information access. Figure 2-25A illustrates the TDRSS network with a single TDRS ground station (assumed to be located at Rosman, N.C.), the associated STDN ground network, and a central network control facility located at GSFC. Automated and hardline interface links exist between all elements of the central ground network facility to facilitate fast response time and real-time operations. They are compatible with and emphasize the objectives of real-time communications and operations and establish the foundations for developing the system with minimum impact on existing and planned facilities and organizations.

The network is compatible with the system concept shown in Figure 2-24. It consists of a Network Operations Control Center (NOCC), a TDRS Spacecraft Control Center (TDRS CON), a Ground Station (GS), two tracking and data relay satellites (TDRS), and NASCOM linking all of the system components.

The inputs to the system are the commands or command requests from the User Control Centers (UCC), the scheduling inputs from NOCC and the user spacecraft responses to these commands. The commands or command requests include spacecraft tracking, housekeeping telemetry, orbital maneuvers, and experiment telemetry. As seen by the sources of the inputs given above, the system is two-way with inputs received at both ends. The outputs of the TDRS system are the commands as processed by the NOCC, TDRSCON, and the GS, and also the telemetry and tracking responses from the user spacecraft as processed by the TDRS system elements.

Some unmanned spacecraft centers are located at GSFC and the Manned Spacecraft Center is at Houston. For TDRS Ground Stations and User Control Centers remote from GSFC, ground communications channels are provided by the NASCOM system. This system furnishes all NASA mission control, technical control, and computation centers with access to remote tracking, data acquisition and command stations. The TDRSS network requires a highly automated ground facility including computer control and processing as well as associated software, although the degree of centralization and automation of the data handling system are still undetermined.

Ground link interface definition depends significantly on the diversity of the ground elements. The degree of ground station separation will depend largely on the data handling requirements of broadband users, the need for data processing facilities and the costs and real-time limitations of long

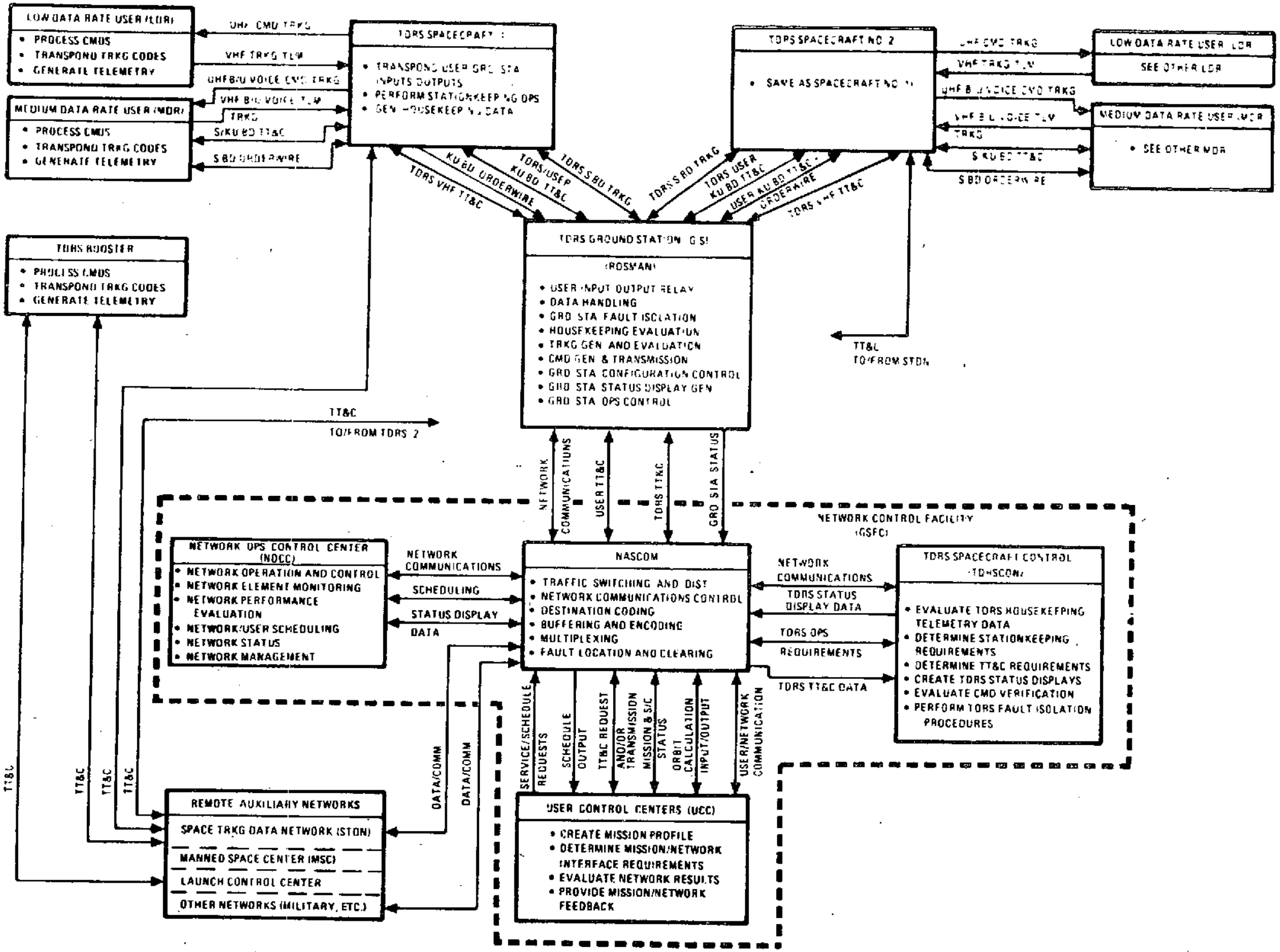


Figure 2-25A. Primary System Elements and Their Operational and Functional Interfaces line transfer and processing of data. Commands will be generated at the user control centers and forwarded directly through NASCOM to the TDRS Ground Station and appropriately formatted for transmission to the spacecraft. A TDRS Ground Station is shown at Rosman.

Functional procedures that would permit real-time operation are, for example: (1) commands generated in the user and TDRS control centers; (2) commands transmitted directly to a communications processor (at GSFC) for multiplexing and priority routing; (3) high-speed MODEM and encoding performed; (4) transmitted via NASCOM to the RF ground station (e.g., at Rosman); (5) high-speed MODEM and decoding at the ground station; (6) ground station buffering and routing for transmission to the TDRS spacecraft. Similar operations are performed in reverse (decoding, demodulation, demultiplexing and re-encoding at the ground station, transmission via NASCOM to GSFC for high-speed MODEM and data decoding and routing), for return data, housekeeping , tracking, verifications, etc. The interfaces and functional relationships shown in Figure 2-25A are compatible with these desired real-time functional procedures.

2.2.2.1 NASCOM

The heart, literally of the system is NASCOM, shown in Figure 2-25B All of the system components shown in Figure 2-24 interface with it, and all inputs whether from the UCC, internal to the TDRS system, from the user spacecrafts, or from auxiliary networks, such as STDN, DSN, or military facilities pass through it.

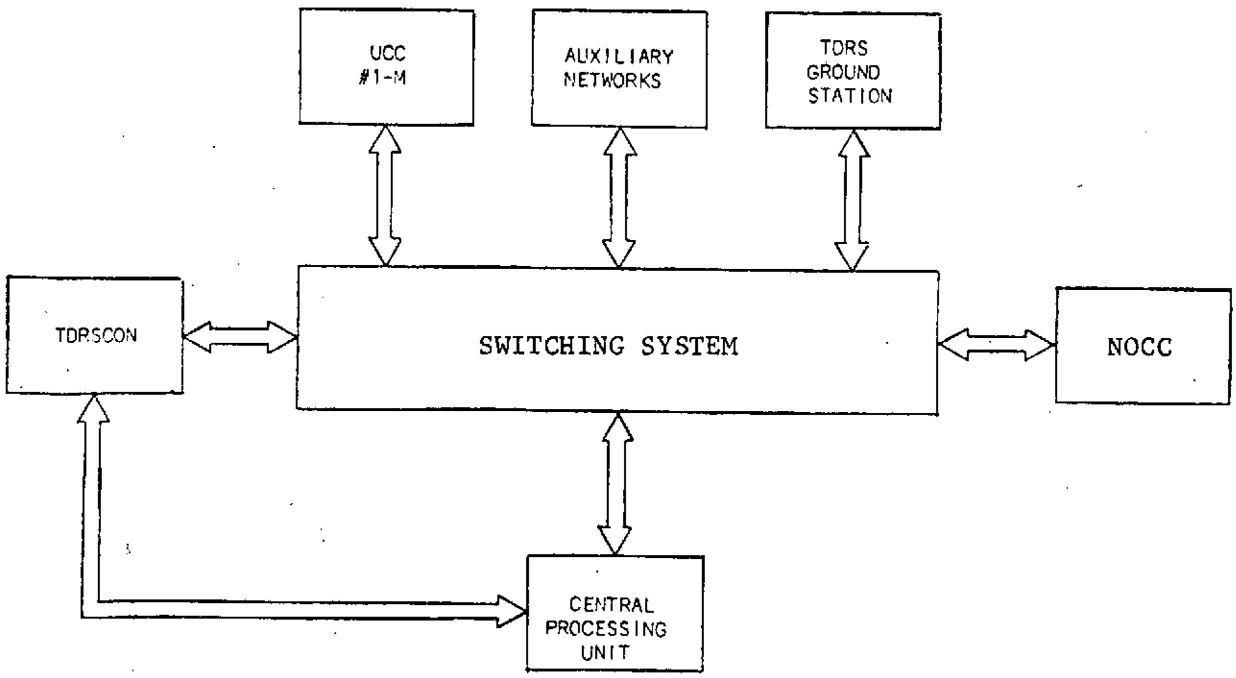


Figure 2-25B. NASCOM

NASCOM is a centrally managed system for all ground communications requirements of the STDN and TDRSS networks. The basic arrangement provides all mission control, technical control, and computation centers with access to remote tracking, data acquisition, and command stations. This access, primarily for launch insertion, orbital flight, and recovery operations, is provided over the entire globe. All communication links are passed through a central switching point located at Goddard Space Flight Center. When in full operation, NASCOM consists of a combination of dedicated and switchable communications links ultimately controlled by a central processing unit.

NASCOM operates in four main modes: the check mode, the request mode, the operations mode, and the communications mode. The check mode is a sequence of procedures and internal self-tests to verify the performance of the circuits as a separate component completely devoid of any outside interface. This mode is used in a preventative maintenance role and also to check-out any fixes and/or modifications that may be necessary.

The request mode consists of the interconnections between the UCC and NOCC, between NOCC and TDRSCON, and between any other components to confirm or deny a request for access to the system. Procedures and information flow for this mode will be set forth in a NASCOM procedures manual to be supplied to all potential system users.

The operations mode is instituted as a result of a confirmed request and is the direct connection of the UCC to the TDRS ground station (GS) The real-time operations mode will be provided by direct command via via NASCOM (with NOCC scheduling input) to the Ground Station. The USS will then communicate directly with the user spacecraft or generate information which the GS can use to command the user spacecraft and retrieve the desired data.

The last mode is the communications mode and is used by the system elements, the UCC, and any auxiliary networks to communicate with each other. This mode is separated from the request mode due to the nature of the information being transferred and the procedures used. This is analogous to asking for information about a service as compared to asking for the use of the service. The former is informal while the latter must, of necessity, be formal.

Information may be carried through the transmission system in its original form at baseband, or signal converters may be used to change it to a form more suitable for transmission. MODEMS are then required at each terminal. Message switching techniques include digital data transmission. Messages are routed by using identifying addresses at the beginning of each message. The system is computer-controlled, employing NASCOM digital computers at the switching centers to route messages and digital data on voice bandwidth circuits.

The NASCOM Communications Control and Switching Facility is shown in a central position because its responsibility is to manage, control, switch, code, and distribute all communications from one element to another in a format appropriate to that destination element. The functions and capabilities of NASCOM are considered to include:

1. Traffic switching and distribution
2. Network communications control
3. Local and remote communications distribution
4. Destination coding
5. Computerized message switching
6. Formatting, buffering and encoding
7. Multiplexing
8. Fault location and clearing

2.2.2.2 Network Operations Control Center (NOCC)

The Network Operations Control Center (NOCC) is the network manager and coordinator of all network activities. Its interfaces via NASCOM are for network communications and network operations control, scheduling and status display. The network control center is the coordinating and scheduling interface between the TDRS system and the users, as shown in Figure 2-25C.

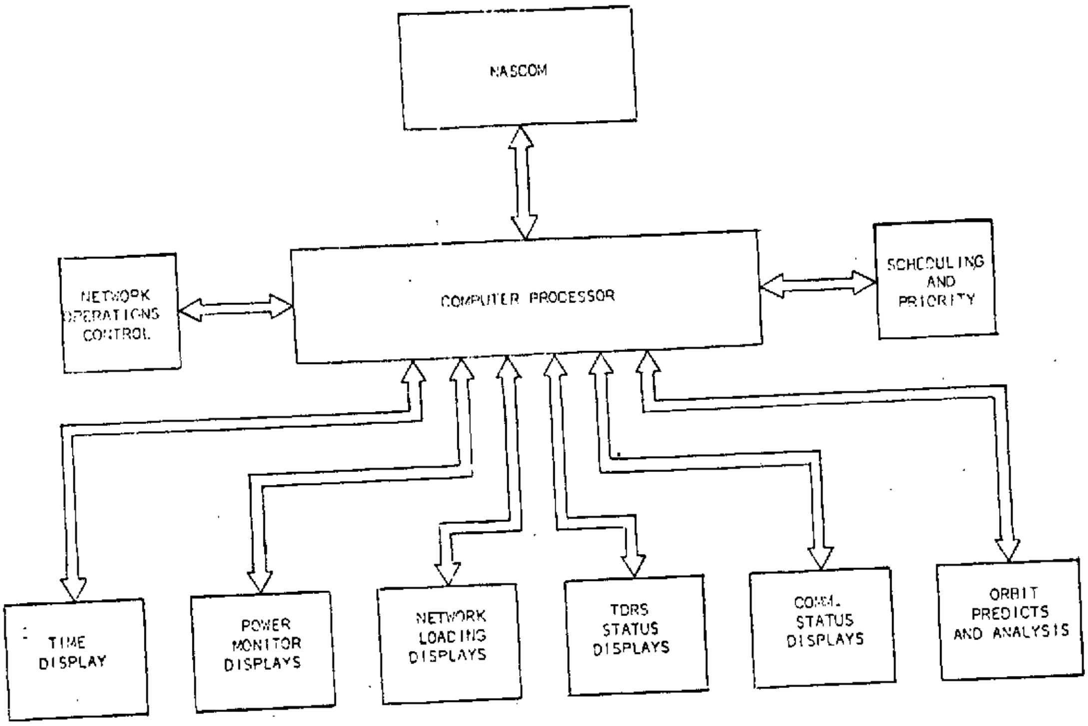


Figure 2-25C. Network Operations Control Center (NOCC)

Routine requests for the use of the system are received by NOCC via NASCOM from the prospective users. Real time commands are sent directly via NASCOM to the command processor at GSFC for processing and routing to the Ground Station. NOCC will have available to it real time displays and/or print-outs of the present system status and projected future use. Time slots will be assigned to a new user request based on the system load (present and future), the nature of the user (military, high priority, emergency, etc.), the percentage of the system needed to fulfill the present request, the need for real time control, the format of the command data (directly generated by UCC or a need to be generated by the GS, the format of the return data, the accuracy of tracking desired, and any special spacecraft attributes.

The functions and capabilities of NOCC are considered to include:

1. Network operations and control
2. Network element monitoring (quick-look monitoring)
3. Network performance evaluation
4. Network/user scheduling
5. Network status and display (TDRS spacecraft, ground station, communications
6. Network management and element coordination

To accomplish the above tasks, NOCC will need real time status reports of the system, which include, but are not limited to, elements such as:

- All present user orbits
- TDRS positions (both satellites)
- TDRS operational status (full power available, etc.)
- GS operational status (all transmitters available, etc.)
- Number and type of unused circuits available (wideband, etc.)
- Any environmental peculiarities (solar storms, etc.)

The result of the decision process at NOCC will be

- A command time line
- A data retrieval time line
- An output to TDRSCON to initiate the proper system configuration
- A request confirmation to the user
- Outputs to all system components for information purposes

2.2.2.3 TDRS Spacecraft Control Center (TDRSCON)

The TDRS Spacecraft Control Center (TDRSCON) is the responsible manager and controller of the TDRS spacecraft and its operations as a relay for communications service to user spacecraft. As such, its interfaces via NASCOM are for network communications, TDRS status and display, TDRS operations and TDRS telemetry, tracking and command.

The spacecraft control center shown in Figure 2-25D is responsible for the operation of the TDRS relay system. It interfaces via NASCOM communications control with NOCC and the Ground Station and is the authorizing agency for the spacecraft operations, procedures and problems. The configuration of the relay system, including the communications lines dedication, the modems, transmitter/receiver pairs, and antenna assignments for TDRS operation is dictated by TDRSCON requirements (and the concurrence of NASCOM for matters involving communications).

The functions and capabilities of the TDRSCON are considered to include:

1. Determination of TDRS TT&C requirements
2. Command and control of TDRS
3. Evaluation of TDRS housekeeping and telemetry data
4. Evaluation of command and performance verification
5. Maintain TDRS status displays
6. TDRS fault isolation and handling
7. Control and evaluation of TDRS relay operations

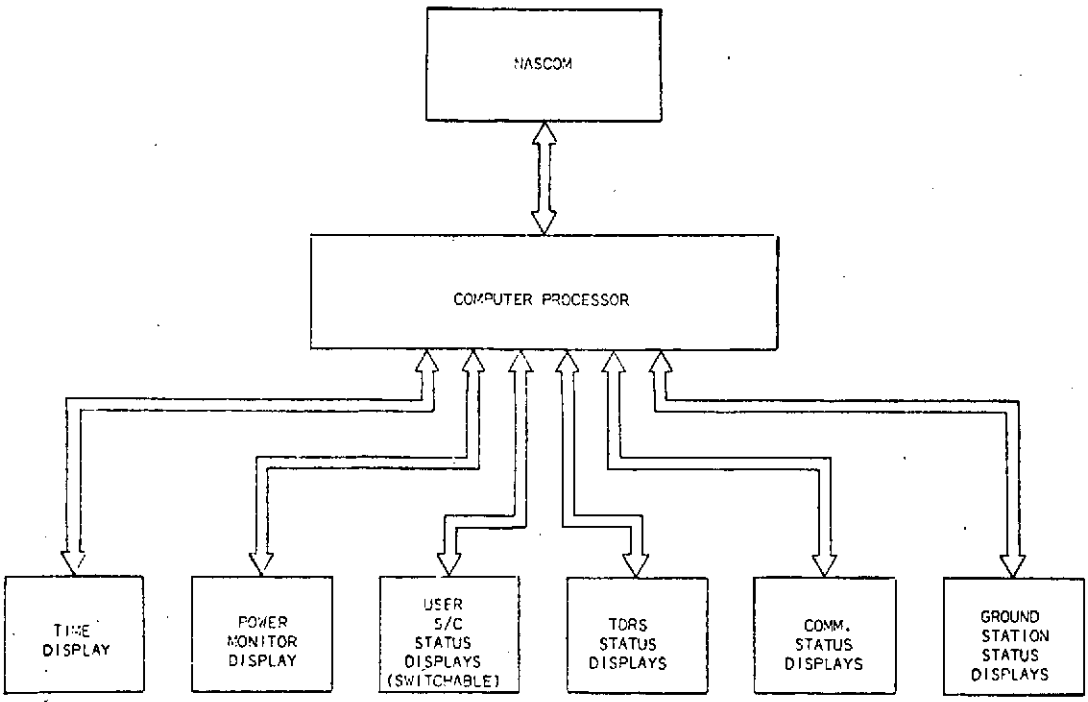


Figure 2-25D. TDRS Spacecraft Control Center (TDRSCON)

2.2.2.4 TDRS Ground Station (GS)

The TDRS ground station is responsible for the management, control and operation of an RF system for generating, transmitting, receiving and handling RF commands and data to and from space and to and from the ground network elements. Its interfaces with the ground network elements through NASCOM are for network communications, user and TDRS telemetry, tracking and command, and for station control. In turn, the TDRS ground station acts as the interfacing element between the user and TDRS control centers and the user and TDRS spacecraft for the RF operations required for the transmission of commands and the reception of telemetry data. The functions and capabilities of the ground station are considered to include:

1. Command and tracking generation and transmission
2. Encoding, decoding and high-speed MODEM operations
3. Command data buffering and routing
4. Command status and command verification multiplexing
5. Data handling, processing and conditioning
6. RF antenna operation and control
7. User input/output relay
8. Ground station configuration and operations control
9. Ground station status displays
10. Ground station monitoring and fault isolation

The TDRS ground station will be a fully automated facility. All switching, frequency selection, antenna patching, data transmission interfaces, modem selection and patching, power control, antenna pointing and tracking, etc., will be computer controlled with the need for station personnel kept to a minimum. There will be a manual override mode provided so as to keep the system functioning, but at a reduced level, in the event of computer failure.

The TDRS ground station is illustrated in Figure 2-25A as located at Rosman, N.C. although other locations may be utilized. The size and complexity of the antennas and other equipments required for the ground station influence its location remote from GSFC.

Figure 2-25B shows a simplified block diagram of the GS. The equipment configuration necessary to support a particular user is put into a format which can be recognized by the central processing unit (CPU). After an execute order is given, the CPU selects the ground station equipment, the equipment parameters, and the interconnection layout. A check is automatically performed on the final configuration by means of local simulation units and monitoring of the subsystem outputs. Upon successful completion a ready message is sent to TDRSCON; also if there is a malfunction or degradation anywhere within the system, this fact is relayed to TDRSCON for action.

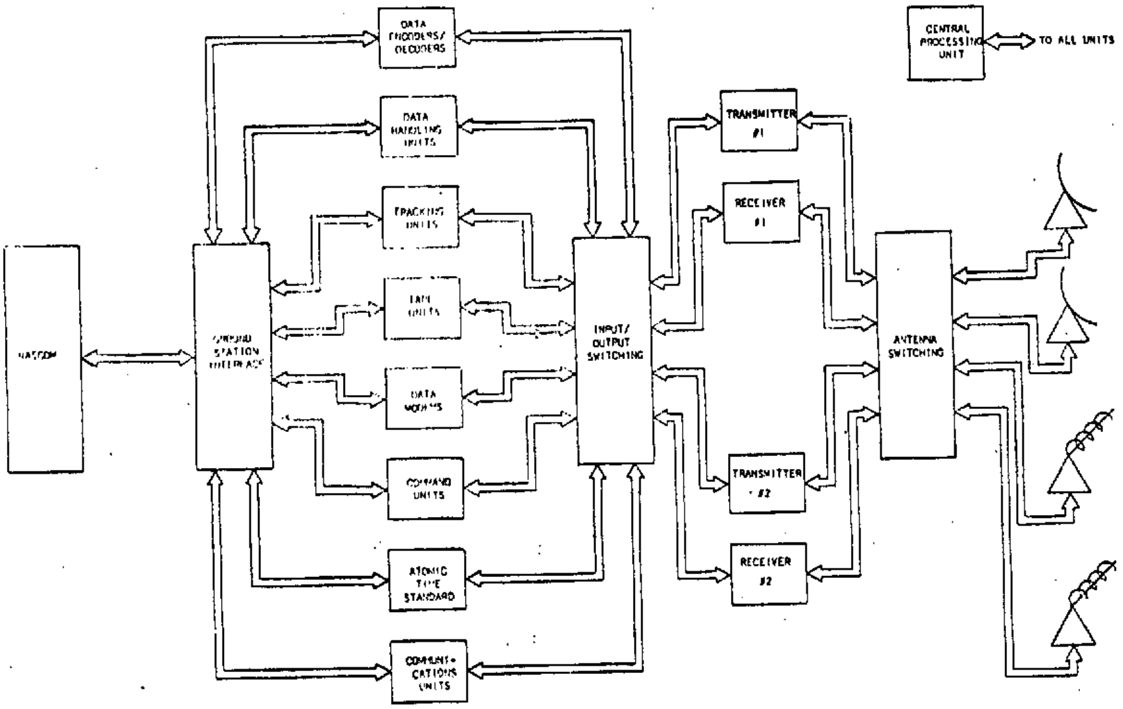


Figure 2-25E. TDRS Ground Station (GS)

The interfaces with the ground station are for the two-way communications of TDRS S-band tracking, user and TDRS Ku-band TT&C, a down link Ku-band orderwire, and TDRS VHF TT&C information. The interface links with the LDR user spacecraft are for a UHF (forward link) TDRS transmissions and user receiving of command and tracking information and a VHF (return link) user transmission and TDRS receiving of tracking and telemetry data. The interface links with the MDR spacecraft are for: (1) a two-way (forward and return link) transmission and receiving of TT&C information; (2) a two-way S-band orderwire, and (3) a backup interfacing link consisting of a UHF (forward link) TDRS transmission and user receiving of voice, command, and tracking information, and a VHF (return link) user transmission and TDRS receiving of voice, telemetry and tracking information.

2.2.2.5 User Control Centers (UCC)

The User Control Center (UCC) is the responsible manager and controller of its dedicated user spacecraft and recipient and evaluator of its mission results. As such, its interfaces via NASCOM are for network communications, user spacecraft status and display, user spacecraft mission operations and control, and user spacecraft telemetry, tracking and command. These require interface relationships for the flow of service and schedule requests, status information, tracking and orbit data, and for real-time communications. The functions and capabilities of the UCC are considered to include:

1. Determination of user mission profile and requirements
2. Command and control of user spacecraft
3. Evaluation of user housekeeping and telemetry data
4. Determination of user TT&C requirements
5. Evaluation of command and performance verification
6. Maintain user spacecraft status displays
7. User fault isolation and handling
8. Mission payload data handling
9. Control and evaluation of user spacecraft performance in the relay interface

The interface between the user control center and the remote TDRS ground station is very sensitive to the extent of separation of UCC processing and control functions and facilities. One option assumes that user spacecraft outputs are signal conditioned at the ground station before transmission to GSFC. A message switching ground link interface configuration may then be utilized. In this configuration several data management functions as well as signal conditioning are performed at the ground station to assure time correlation and quality of all user data and to reduce various circuit-switching constraints: limited data rates, time-delay variations, NASCOM telemetry link scheduling requirements, data recovery responsibility and also equipment duplication at the data user facility. The data recovery functions may be performed in hardware or software depending on the particular interface design, and require considerable computer facilities. They include, for each discrete receiver output, user frame detection and synchronization, station time tagging, formatting, satellite and station identification, destination coding, synchronous transmission and message multiplexing, encoding, and retransmission, if required, etc. Some of these functions may be part of the NASCOM terminal located at the ground station, mainly functions for preparation for transmission, switching, and ground link protection (e.g., formatting, multiplexing, buffer speed conversion, error encoding, forward error corrections, retransmission).

2.2.2.6 Relay Satellites (TDRS)

The space group of elements consists of the TDRS spacecraft (east and west operational units) and the user spacecraft (20 LDR and 2 MDR spacecraft per TDRS). The TDRS spacecraft interfaces directly with the ground station and with the user spacecraft. It is responsible for the relay operations to accomplish the interface linking of user spacecraft operations to the user via the ground station and NASCOM.

The functions and capabilities of the TDRS spacecraft are described in detail throughout this report. The principal functions and capabilities are briefly summarized as including the transponding of user spacecraft and ground station inputs and outputs, the performance of stationkeeping operations, the generation of housekeeping data, and the performance of acquisition, handover, tracking and station transfer operations. The functions and capabilities of the user spacecraft include the receiving and processing of commands, the generation and transmission of telemetry data, the transponding of tracking codes and cooperative performance in acquisition, handover, tracking, and stationkeeping operations.

2.2.2.7 Remote Auxiliary Ground Network Elements

Additional interfaces exist between the auxiliary or remote ground network elements and the TDRS spacecraft and the GSFC Network Control Facility (through NASCOM). These remote elements consist of the Spacecraft Tracking and Data Network (STDN) tracking stations, the Manned Space Center (MSC) at Houston, the Launch Control Center (LCC) at KSC and other network elements such as remote user control centers, military elements, etc. The interfaces between the spacecraft and these remote ground elements are for tracking, telemetry and command. The interfaces between the spacecraft and the remote ground station were previously described.

The interfaces between NASCOM and the remote ground network elements are essential operational and functional components of the overall system. The interfaces between NASCOM and STDN, MSC, LCC, etc., are for the flow of commands and data. The interfaces between NASCOM and the remote TDRS ground station (Rosman or elsewhere) were discussed above in relation to the ground station. They will generally consist of tracking, telemetry and command information on both the TDRS and user spacecraft, and voice coordination and utilization. A STDN control center in the GSFC facility will have an interface link through NASCOM to the various STDN tracking stations throughout the world. The principal STDN stations that will be utilized for the Delta 2914/TDRS boost and deployment phases of the mission consist of Rosman, Orroral, Tananarive, and Guam.

The configuration and interfaces of the ground and space elements of the future TDRS system for supporting multiple manned and unmanned user spacecraft will be undergoing continuing investigations by NASA and industry. Some aspects are relatively unsettled as the developments and requirements of the future system undergo conceptual, design, and analytic considerations. Some of the problem areas which will influence the interface and operational relationships between network elements are: (1) the number, location, configuration, and operation of the integrated STDN stations and network; (2) the number, location, configuration, and operation of TDRS ground stations; (3) the number, configuration, location, size, and degree of autonomy and sophistication of user control centers and the extent of concentration at GSFC; (4) the degree of concentration, separation, or sharing of data handling and processing; and (5) the degree of automation of system element operations. The system concept, interface, functional and operational analyses project the philosophy of real-time operation, maximum use of existing and planned organizations and facilities, minimum impact of introducing new developments and, finally, cost-effective operation of a TDRS system.

2.2.3 TDRSS Functional Analysis

A detailed analysis of TDRSS functions and operations was conducted and detailed functional flow diagrams were developed to a third/fourth level of operations. These are shown in Figures 2-26 through 2-81. A number of functions are repeated as required throughout the mission (such as housekeeping) in both preoperational and operational phases, the generation and transmission of commands from the control centers through the Ground Station to the User and TDRS spacecraft, and the verification of commands and performance. Some operations are performed simultaneously, and alternative operations may be performed in some cases. Significant variations in operations between the operations of an LDR User, MDR User and TDRS spacecraft are accounted for by providing separate functional flow diagrams for each. Since more detail is provided than in distinct second, third, or fourth level functional flows, the diagrams reflect combined second/third and third/fourth level functions and operations.

The verification capability shown in the diagrams implies that a logic or technique is available for returning to the Ground Station from the spacecraft a command execute verification signal or for rejecting the given command and thus requiring a new or corrected command. This requirement for verification may not be necessary at all times, such as when telemetry data is sent upon command and its transmission verifies itself, or when an antenna command is subsequently indicated by the lock-on and the flow of data.

The flow diagram for each mission function is presented as though separate and complete in itself. This causes apparent repetition and redundancy of operations. In a representative TDRS sequence of operational phase mission operations, presented in the next section, a representative or typical flow of such operations is given.

2.2.3.1 Top-Level Functional Flow Diagram

Figure 2-26 shows the TDRSS top-level function flow diagram, with the three main areas of system operation; prelaunch operations, preoperational launch and deployment operations, and the operational mission operations as a relay spacecraft on station.

2.2.3.2 First Level Functional Flow Diagrams

Figures 2-27 and 2-28 respectively show the first level functional flow diagrams for the preoperational and operational phases of the TDRS mission. The prelaunch operational phase is dominated by the Delta 2914 and TDRS preparations for testing, transporting and mating the booster and spacecraft elements and the checkout and countdown operations at the launching site at KSC. This will follow established procedures performed in previous Delta spacecraft launches.

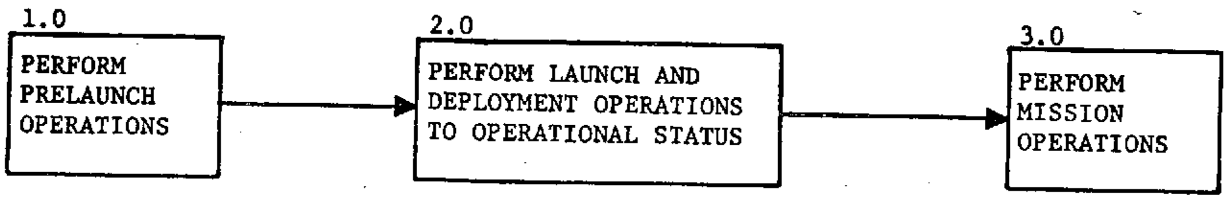


Figure 2-26. Top Level Functional Flow Diagram

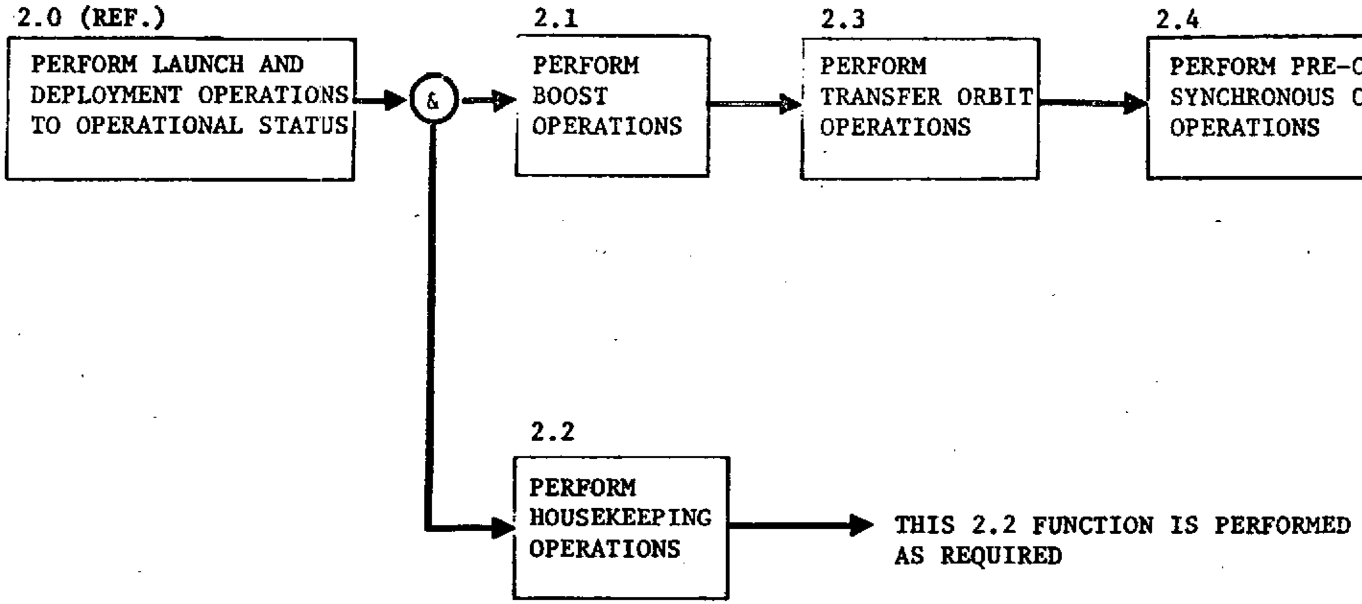


Figure 2-27. FIRST LEVEL FUNCTIONAL FLOW DIAGRAM (2.0 PERFORM LAUNCH AND DEPLOYMENT OPERATIONS TO OPERATIONAL STATUS)

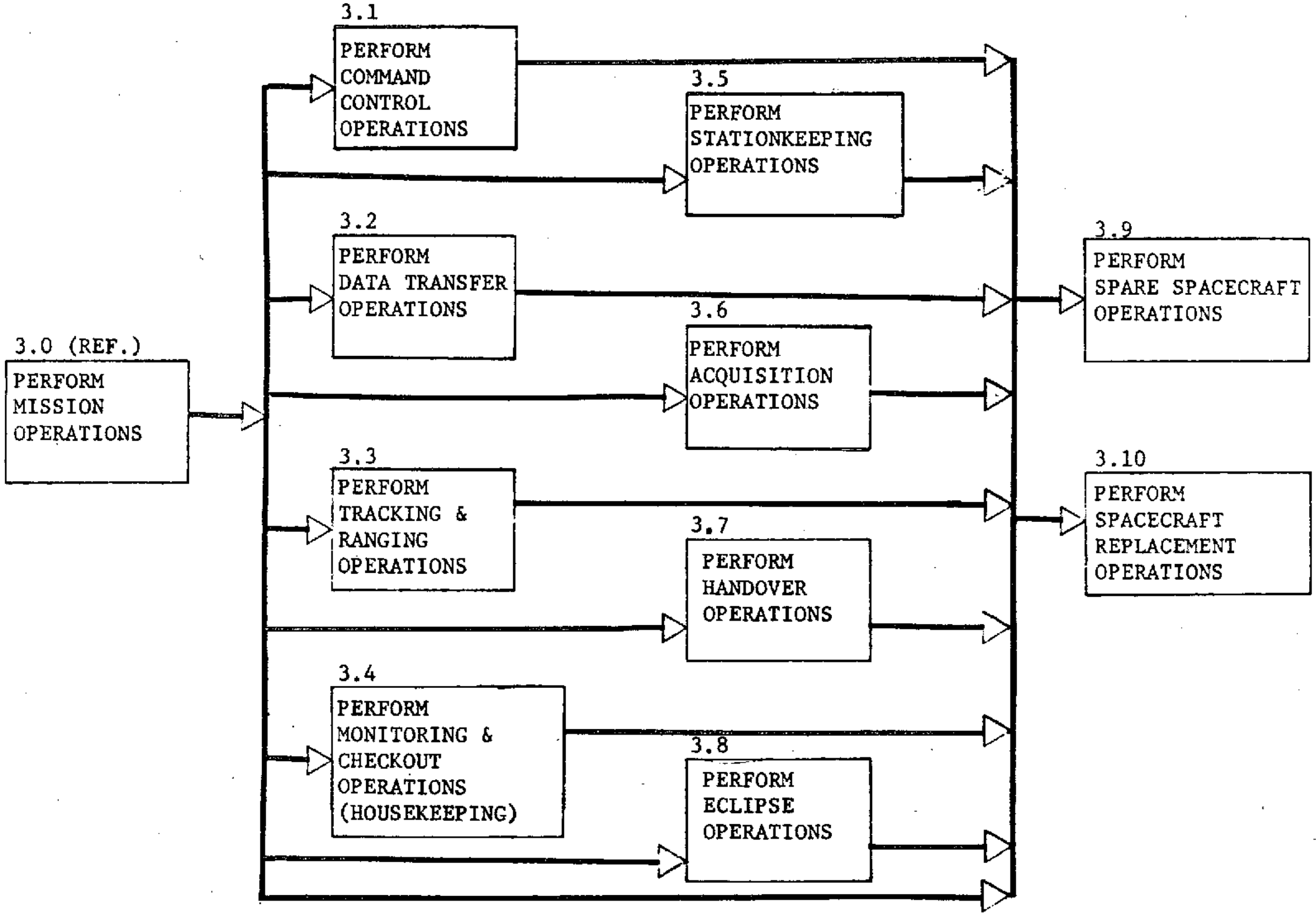


Figure 2-28. FIRST LEVEL FUNCTIONAL FLOW DIAGRAM
(3.0 PERFORM MISSION OPERATIONS)

The preoperational phase involves three distinct phases of operations; boost, transfer orbit, and the operations performed in the post-transfer orbit at synchronous altitude to achieve operational status. The launched vehicle must be tracked and monitored by housekeeping operations throughout this flight to assure proper performance and condition.

The operational mission, after achieving proper station, is to perform as a relay to service User spacecraft at low earth orbits with two-way communications to the TDRS Ground Station and to their respective Users. A concurrent responsibility is to assure the cooperative performance and condition of the TDRS to perform this relay function throughout its lifetime. A third responsibility is to assure the cooperative, controlling, monitoring and handling performance and condition of the ground network elements. The combined objective is to achieve continuing, effective, real-time operations of the system for five years. Hence in Figure 2-28 the operational mission is shown to involve, in a sequential and/or parallel manner, all the desired functions of a TDRS system, namely, command and control, data transfer, tracking, housekeeping, acquisition, handover, station keeping eclipse operation, station transfer and spare spacecraft operation.

In both preoperational and operational phases of the mission, detailed functional flow diagrams were developed at the second, second/third, and third/fourth levels. These show alternative sequences of operations, concurrent as well as sequential, for both real-time and non-real-time operations.

2.2.3.4 Second Level Functional Flow Diagrams

Boost Operations. The operations in the boost phase of the mission up to entering the transfer orbit involve Stage I and II operations, parking orbit operations, Stage II restarting and Stage II operation through burnout and payload separation before insertion into the transfer orbit. The mission profiles and timelines for these operations are described in detail in Section 2.1. Housekeeping operations are performed as required throughout this phase of the mission and are detailed in Figure 2-30. These involve ground based system monitoring, tracking and command and control operations, as well as on-board system monitoring and checkout leading to correction operations as required.

Transfer Orbit Operations. The transfer orbit profile and timeline, presented in Section 2.1, describe the sequence of operations involved in moving through the transfer orbit to the synchronous altitude and the preparations for achieving proper attitude for apogee motor burn. Figure 2-31 shows the second level functional flow diagram for these operations. Involved are the functions to achieve rotation control, to achieve proper attitude and stabilization by spacecraft precession, to determine and measure this attitude and to maintain condition by continuing housekeeping operations.

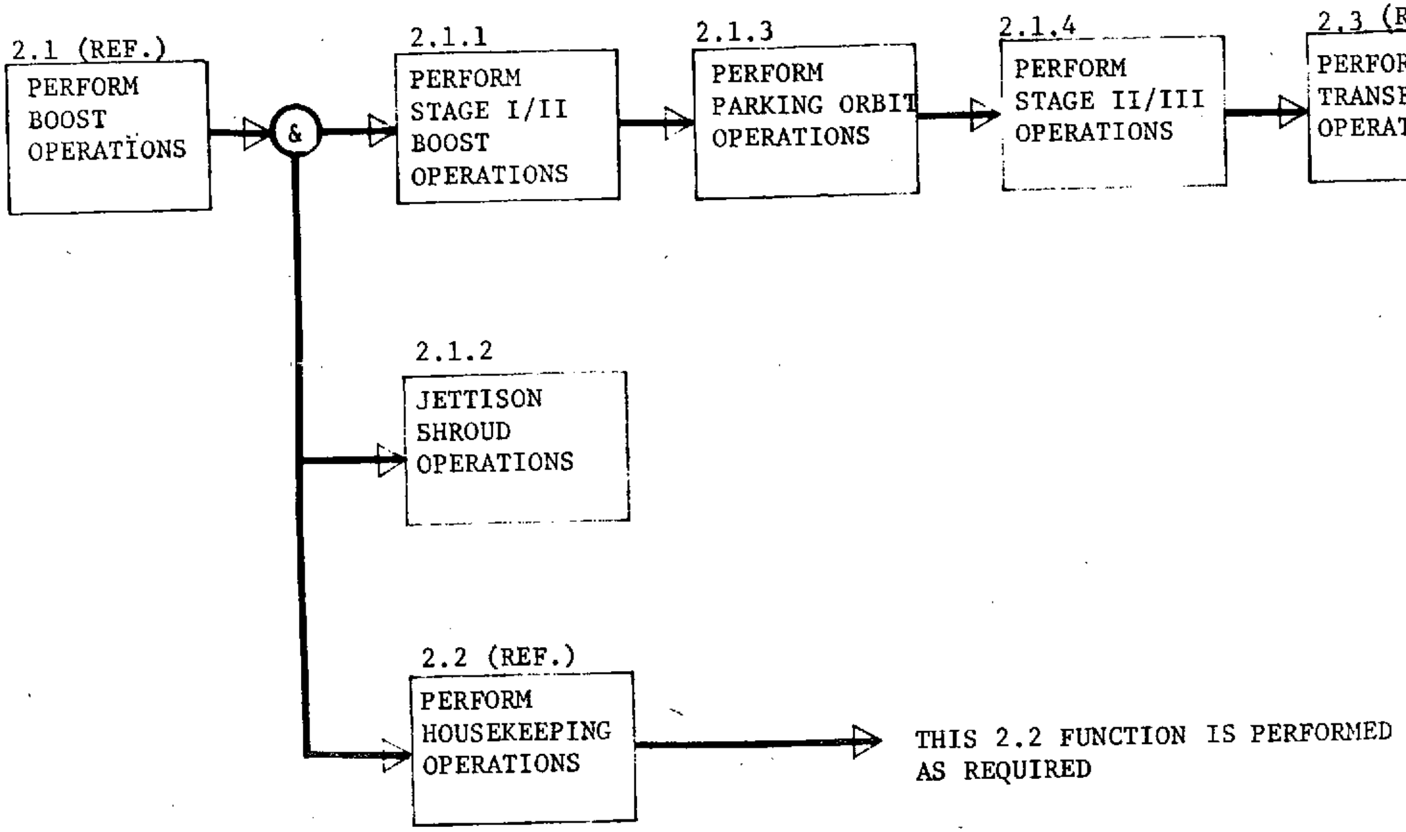


FIGURE 2-29 SECOND LEVEL FUNCTIONAL FLOW DIAGRAM
2.1 PERFORM BOOST OPERATIONS

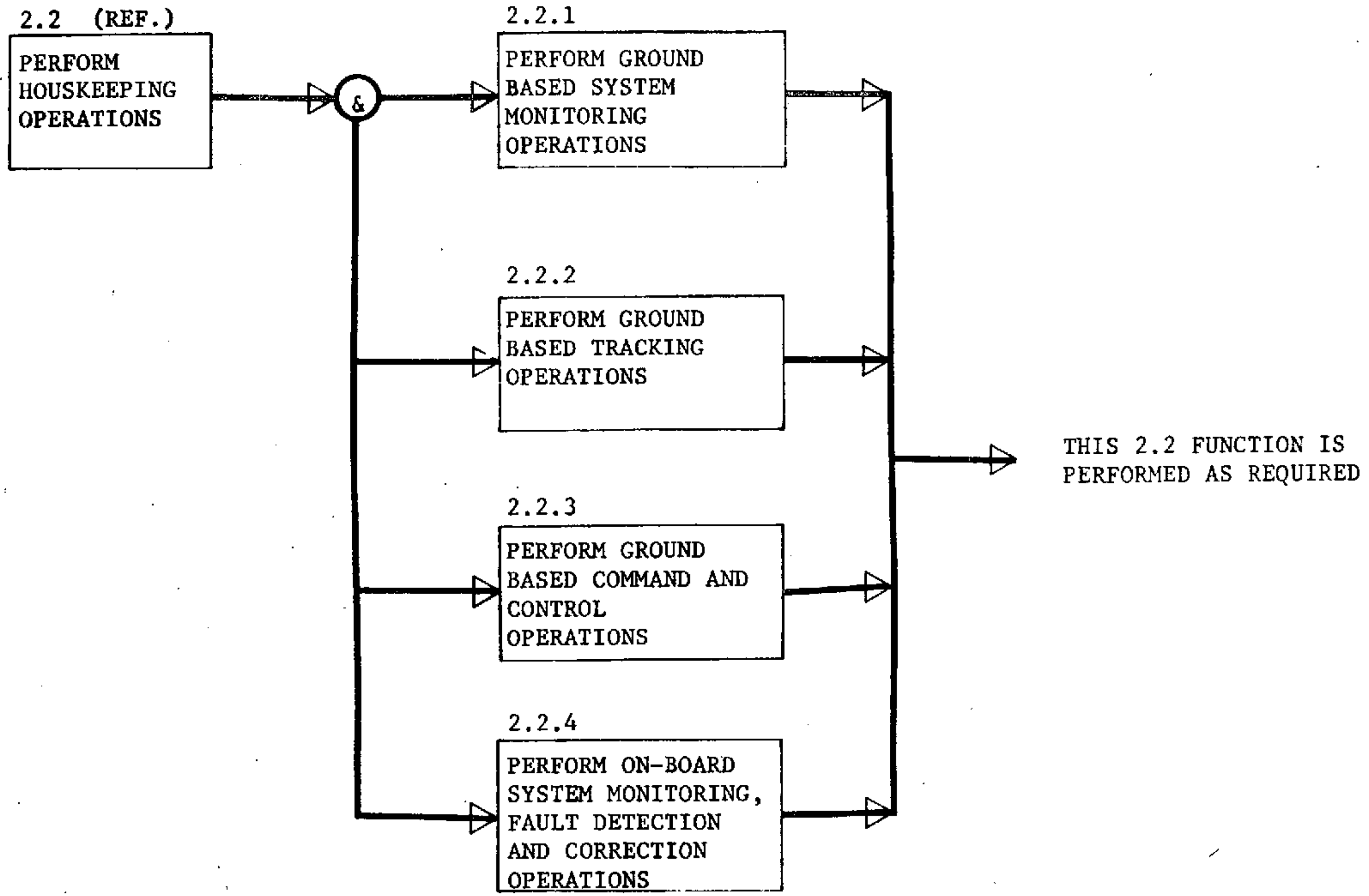


FIGURE 2-30 SECOND LEVEL FUNCTIONAL FLOW DIAGRAM
2.2 PERFORM HOUSEKEEPING OPERATIONS

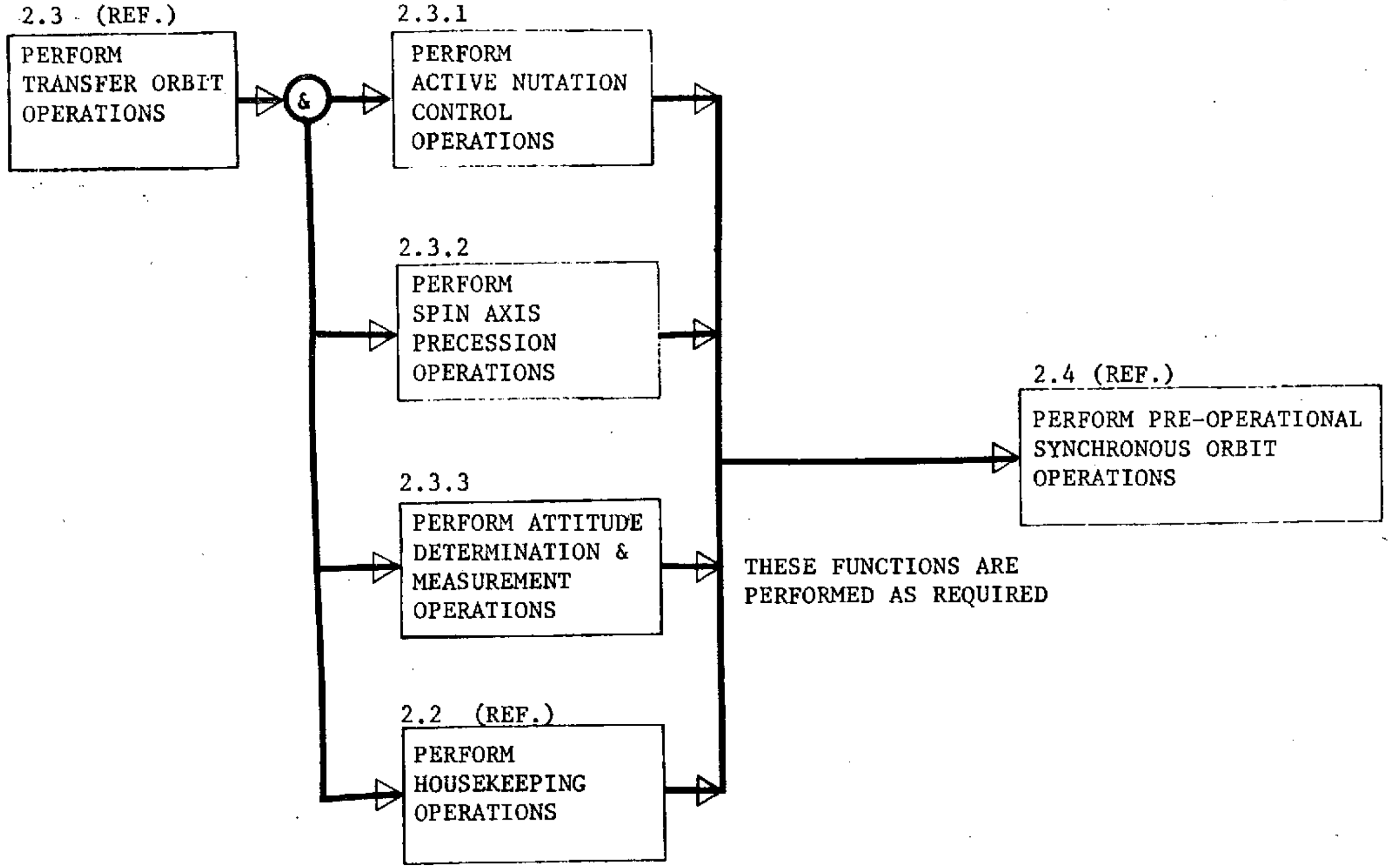


FIGURE 2-31 SECOND LEVEL FUNCTIONAL FLOW DIAGRAM
2.3 PERFORM TRANSFER ORBIT OPERATIONS

Pre-Operational Synchronous Orbit Operations. Figure 2-32 illustrates the functional flow of operations in achieving the station location. They involve the apogee motor burn, insertion into the synchronous orbit, despin and stabilization, deployment of antennas and solar panels, and drift to the station. As soon as the antennas are deployed, the appropriate User-TDRS-Ground communications links can be activated and information transmitted.

2.2.3.5 Second/Third Level Functional Flow Diagrams

Figures 2-33 through 2-48 provide detailed second/third level functional flow diagrams for each function in the first level flows. In these cases, significant variations exist between the operations of an LDR User, MDR User, and the TDRS, particularly in those operations involving actions of User and TDRS antennas and transponders, to justify separate functional flow considerations. As appropriate in these cases, separate flow diagrams are shown for the Users (LDR and MDR) and the TDRS. Since more detail is provided than in a normal second level functional flow, the diagrams reflect combined second/third level functions and operations. Each functional flow is presented as though separate and complete in itself; the apparent repetition and redundancy of operations are shown for completeness and understanding although common functional box numbers were used where possible for common functions and operations.

Command and Control Operations. A single flow is presented in Figure 2-33 for both LDR and MDR Users; and in another in Figure 2-34, for TDRS. There still are many similarities between them. Except for the TDRS transponding the forward link command to the User, the User receiving and performing the command and transmitting a return link execute verification signal and the TDRS transponding the return link User signal to the ground, the two operations are very similar. Emphasis is placed on the real-time objectives described in the previous sections. The commands are generated in the User or TDRS Control Centers and transmitted directly to a communications processor at GSFC for multiplexing and priority routing, high speed MODEM and encoding. Then, provided with input orbit and scheduling data from TDRSNET, this is transmitted via NASCOM to the TDRS RF Ground Station for decoding, high speed MODEM buffering and routing for transmission to the TDRS spacecraft. Similar operations are involved in reverse for the return link telemetry. At the Ground Station the forward link command is simultaneously transmitted to the TDRS and internally verified by demodulating and comparing the transmitted signal with the recovered signal to permit either terminating the transmission or either retransmitting the command or regenerating a new command. The execution of the command is verified by a return link telemetry signal. The rejection of the command is likewise reported by a return link telemetry signal indicating the User or TDRS decoder does not recognize the erroneous command and requires new decoder status. The return link telemetry in either case is received back at the Ground Station, where it is decoded, demodulated, demultiplexed, and re-encoded for transmission via NASCOM to GSFC for high speed modem, data decoding and routing to the Control Centers (if required).

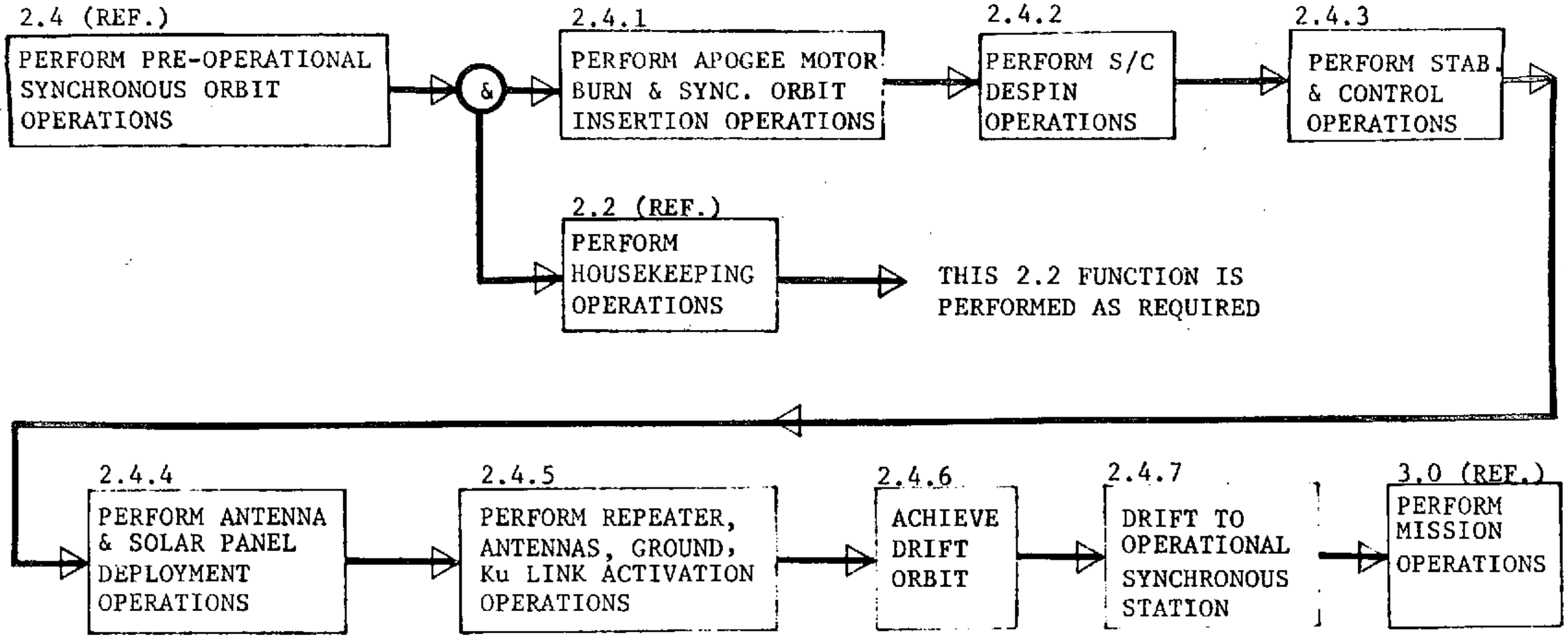
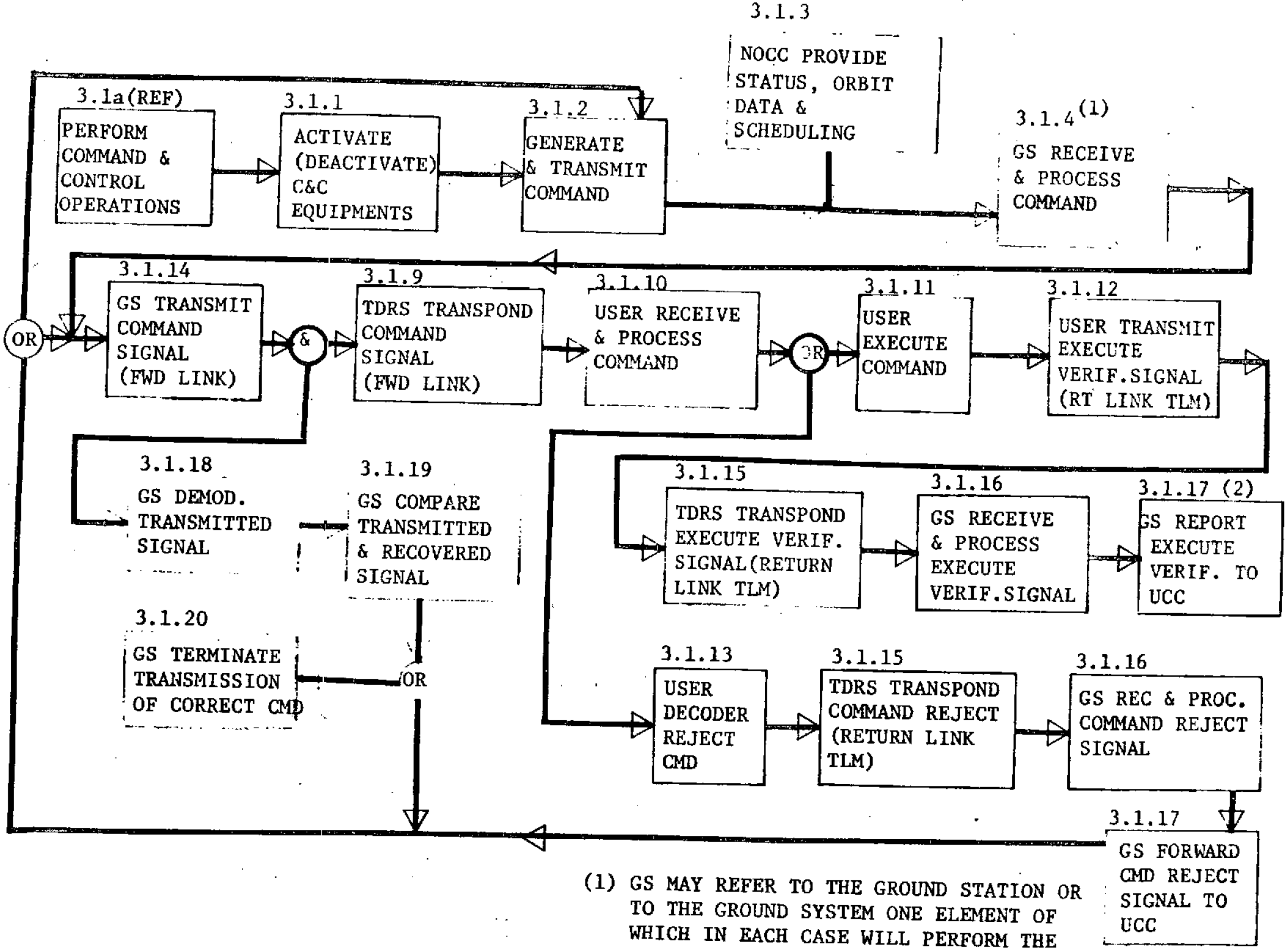


FIGURE 2-32 SECOND LEVEL FUNCTIONAL FLOW DIAGRAM
2.4 PERFORM PRE-OPERATIONAL SYNCHRONOUS ORBIT OPERATIONS



(1) GS MAY REFER TO THE GROUND STATION OR TO THE GROUND SYSTEM ONE ELEMENT OF WHICH IN EACH CASE WILL PERFORM THE INDICATED OPERATION.
(2) IF REQUIRED BY PROJECT CONTROL

Figure 2-33 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.1a PERFORM COMMAND AND CONTROL OPERATIONS - USER

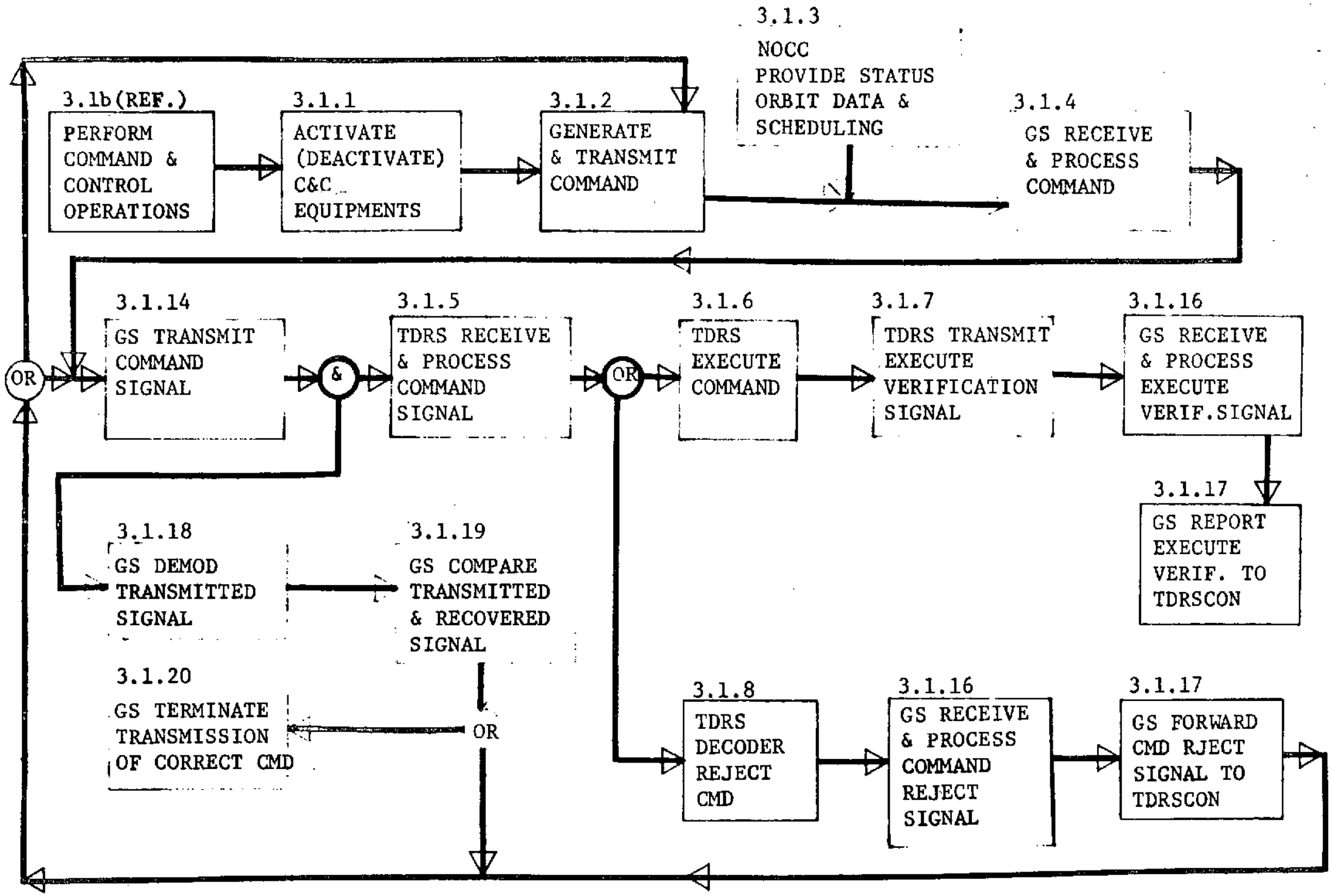


Figure 2-34 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.1b PERFORM COMMAND AND CONTROL OPERATIONS - TDRS

Data Transfer Operations. Figure 2-35 shows that a command is generated at the User Control Center for User data to be generated and/or transmitted. Many of the operations performed by the ground system elements previously described for commands are also performed here. After the User receives and processes the command, he then generates and transmits data to the TDRS where it is transponded to the Ground Station for processing and transmission via NASCOM to the User Control Center. At the flow level indicated, the operations are the same for both LDR and MDR data.

Tracking and Ranging Operations. (1) LDR User. The tracking and ranging flow diagram for LDR Users is shown in Figure 2-36. The UCC generates and transmits a tracking mode in which it has computed the requirements and developed the operational plan. As in the previous cases, it transmits this tracking mode to the Ground Station which processes it for transmission to the TDRS to obtain the desired accuracy, the Ground Station generates and transmits both a TDRS and a User PN ranging code signal. At the TDRS, the TDRS PN ranging code signal is transponded back to the Ground Station where it is processed and reported to TDRSCON. The User PN ranging code signal is transponded forward to the User, transponded back to the TDRS, then transponded back to the Ground and processed and reported to UCC. These operations may be repeated as frequently as required to improve accuracy. A short PN code is transmitted to aid in acquisition; after acquisition a long code is sent to improve ranging accuracy.

(2) MDR User. For the MDR User shown in Figure 2-37 some significant differences in operation are required involving the pointing of the directional MDR and TDRS antennas so as to accurately orient and lock them on to each other. This case assumes acquisition has already taken place and the antennas are oriented but relatively small TDRS antenna adjustments are required to lock on the User for ranging code signal transmission. The operational steps for initial acquisition of an MDR User are described below in the Acquisition functional flow diagram. Thus, after the Ground Station receives and processes the tracking mode, two courses of action may be taken; either generating and sending a TDRS S-band antenna pointing command or a Ku-band antenna pointing command. This uses the S-band tracking link as an alternative back-up link if the Ku-band link is not available. In either case the TDRS antenna is oriented to the User and the status is reported back. Simultaneously with either of these actions, the Ground Station generates and transmits TDRS and User PN ranging code signals which are received, transponded and returned to complete the tracking operation. This is repeated as required.

(3) TDRS. The TDRS is tracked by tri-lateration from the STDN stations. (Figure 2-38) The Ground Station generates and transmits by Ku-band a PN ranging signal. The TDRS may either transpond it by Ku-band to the ground or it may do this at the same time it transponds an S-band range code to the STDN stations. Two or more of these stations may receive this signal and transpond a return range code signal by S-band to the ground where all these signals are received and processed for reporting the tracking data to TDRSCON. The tri-lateration obtains highly accurate tracking measurements.

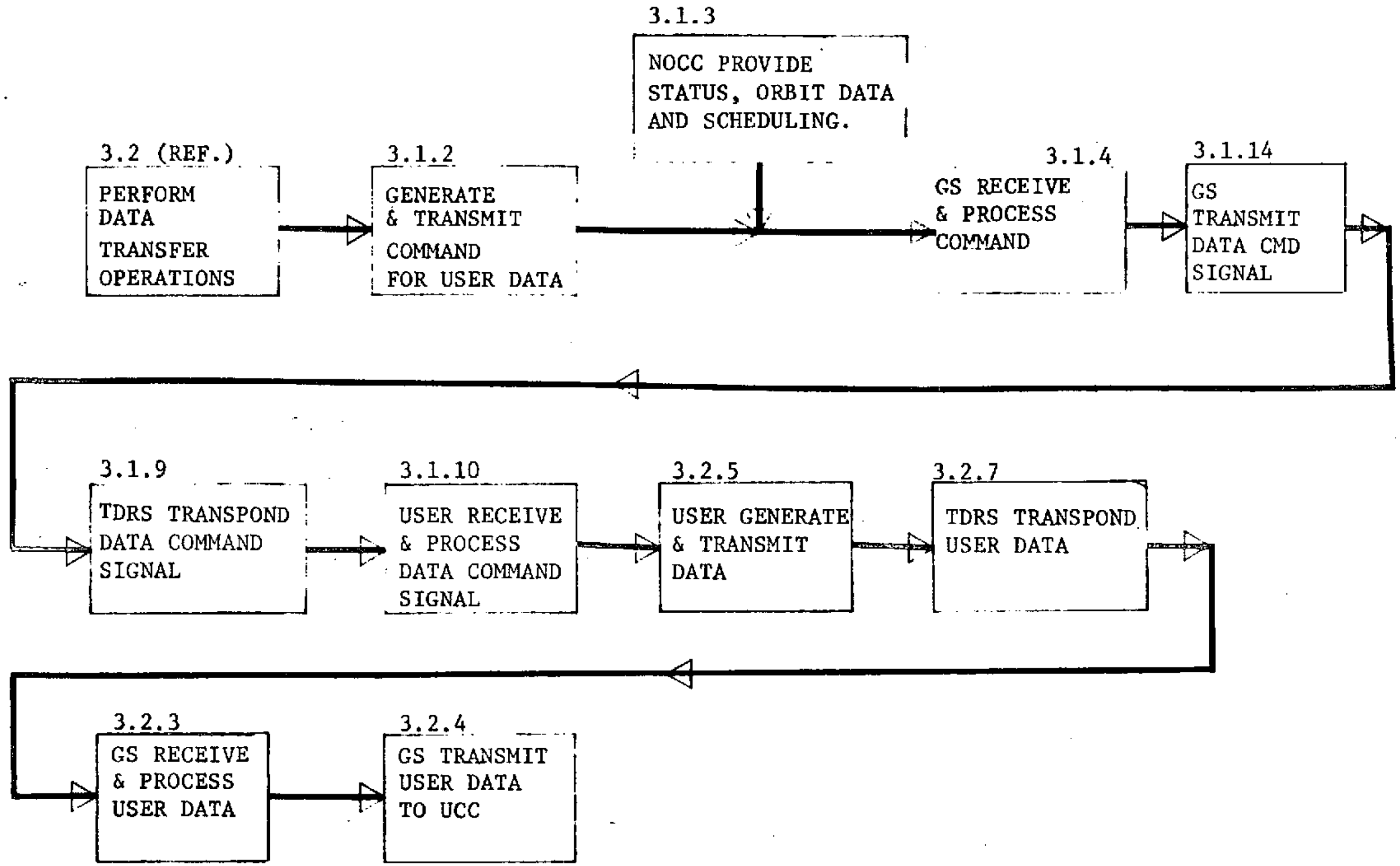


FIGURE 2-35 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.2 PERFORM DATA TRANSFER OPERATIONS

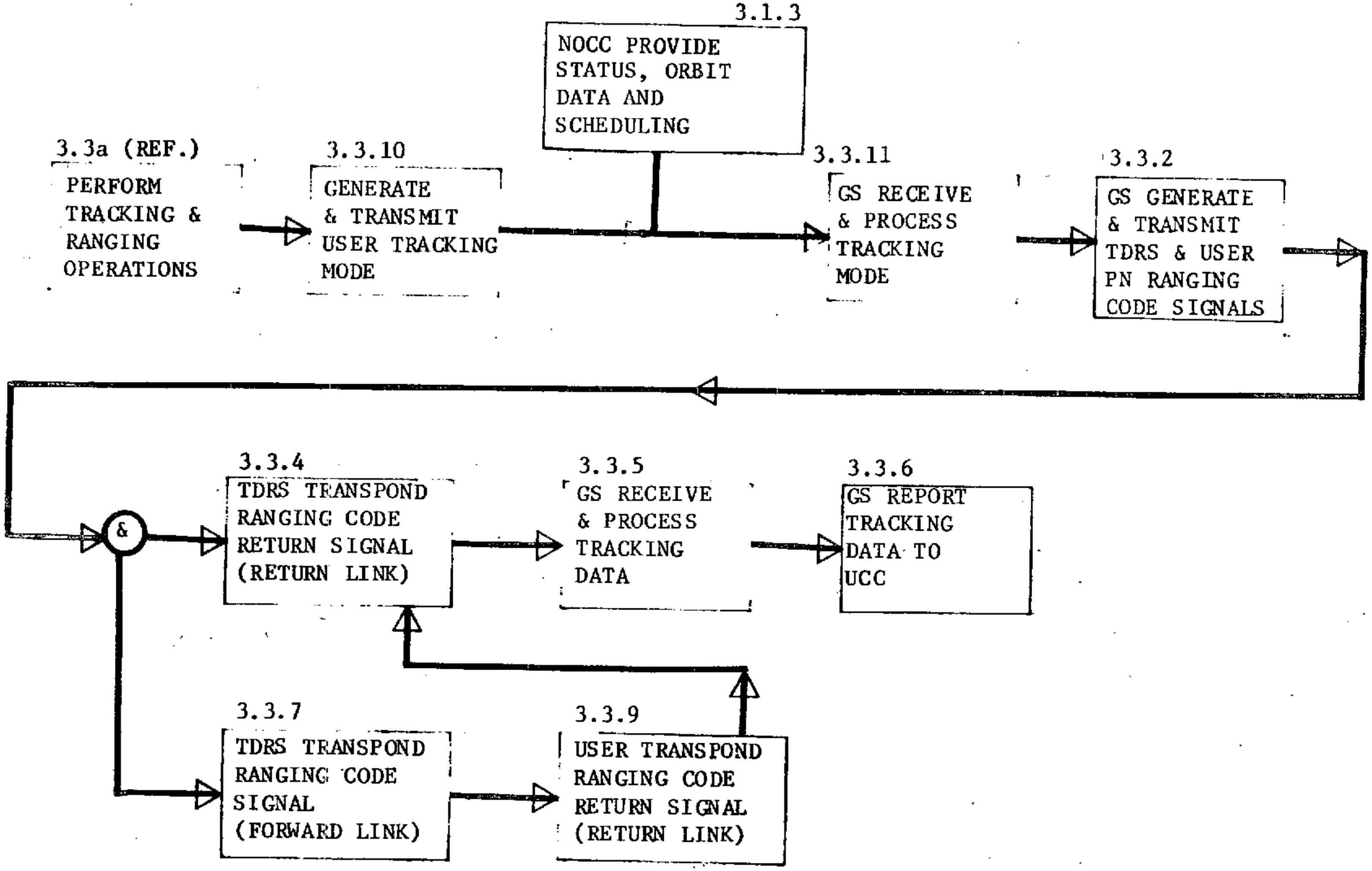
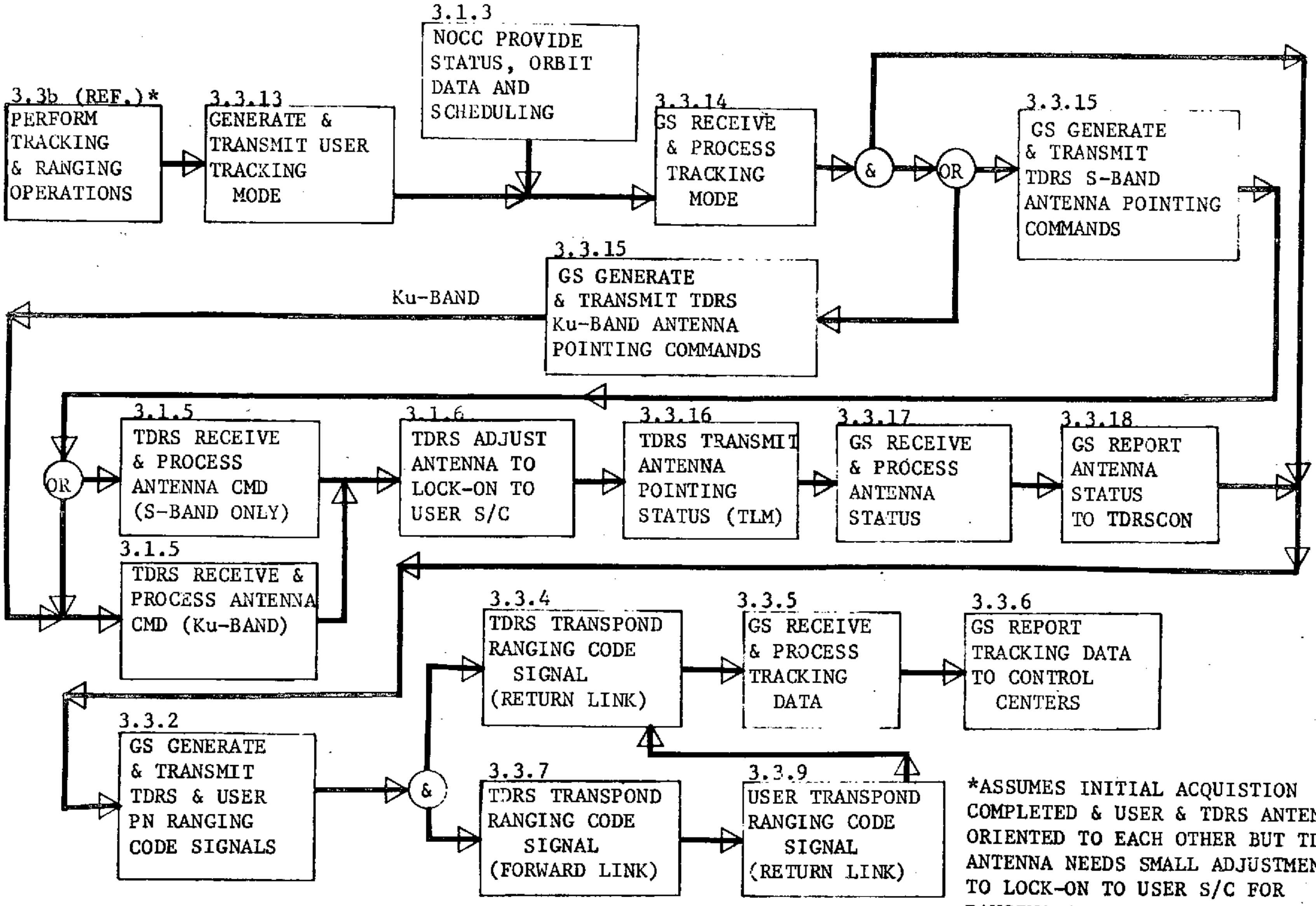


FIGURE 2-36
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.3a PERFORM TRACKING AND RANGING OPERATIONS - LDR USER



*ASSUMES INITIAL ACQUISTION COMPLETED & USER & TDRS ANTENNAS ORIENTED TO EACH OTHER BUT TDRS ANTENNA NEEDS SMALL ADJUSTMENTS TO LOCK-ON TO USER S/C FOR RANGING CODE SIGNAL TRANSMISSION

FIGURE 2-37 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.3b PERFORM TRACKING & RANGING OPERATIONS-MDR USER

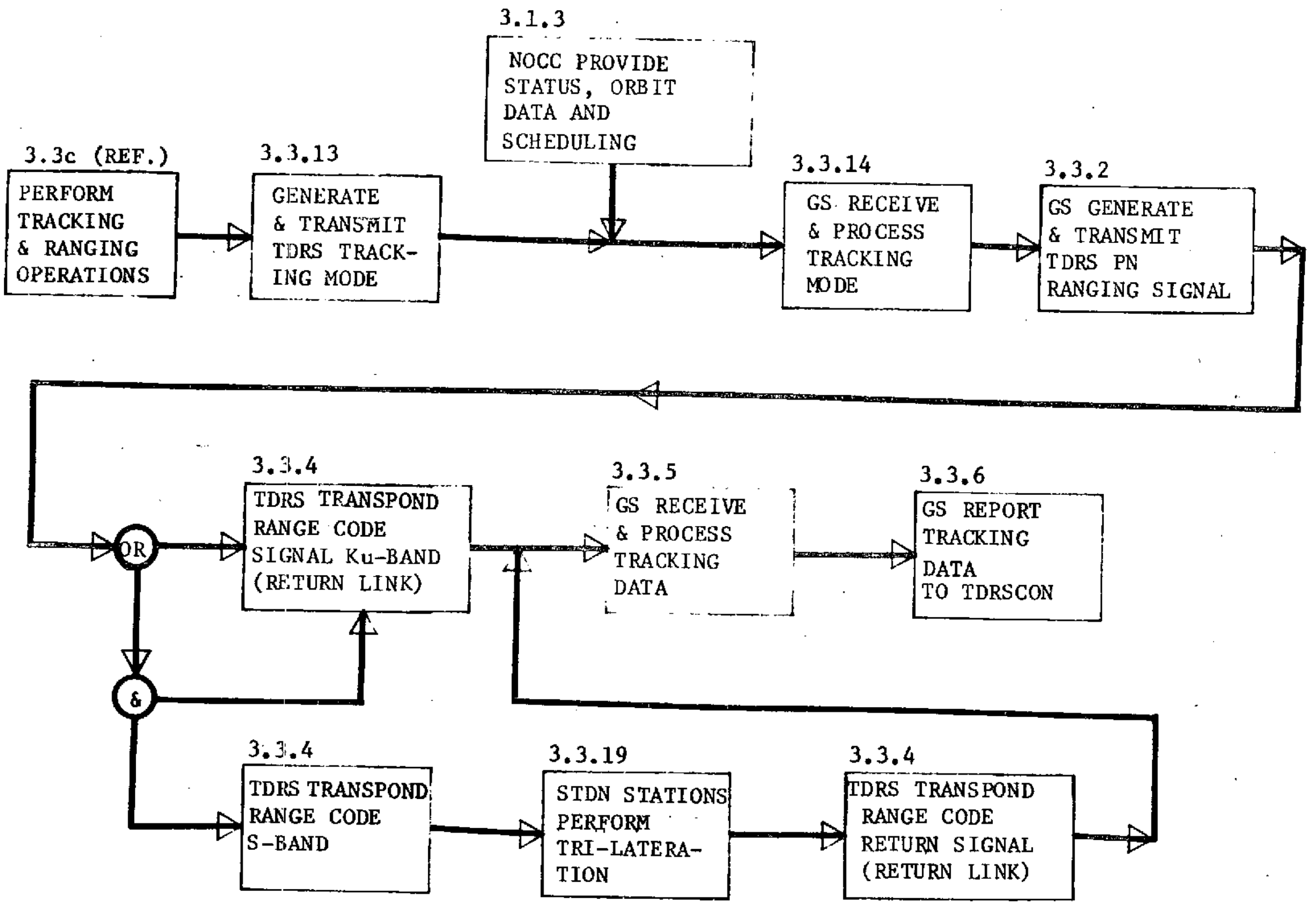


FIGURE 2-38
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.3c PERFORM TRACKING AND RANGING OPERATIONS - TDRS

Housekeeping Operations. Functional flow diagrams for User and TDRS housekeeping operations are shown in Figures 2-39 and 2-40. The operations are straight forward and similar to those for command and control. The housekeeping command transmitted at the Ground Station is on an on/off mode. The housekeeping data is compared at UCC or TDRSCON to a reference of stored data and evaluated. Based upon this evaluation correction commands may be regenerated at the Control Center or retransmitted at the Ground Station.

Stationkeeping Operations. Diagrams for User and TDRS Stationkeeping Operations are shown in Figures 2-41 and 2-42. These are similar to those for other command operations. The Control Centers generate the stationkeeping commands. The Ground Station transmits the delta V maneuver commands to the TDRS, while also demodulating and comparing the transmitted and recovered signals for evaluation and termination or retransmission of corrected commands. The delta V maneuver commands are transponded, executed or rejected, and the execution or rejection verified by return link signals.

Acquisition Operations. (1) LDR User. The diagram for LDR User acquisition operations is shown in Figure 2-43. After the UCC generates and transmits the computed and developed LDR User acquisition mode and the Ground Station receives and processes this program, the Ground Station generates and transmits by Ku-band a carrier signal with the appropriate frequency and a VHF transmitter activation command. This is transponded to the User by VHF forward link where it is received and processed. The User then acquires carrier lock and acquires PN code, bit, and frame synchronization to allow command execution. The User then activates the desired frequency and turns the VHF transmitter on, and returns the carrier with modulation by VHF return link to the TDRS for transponding to the Ground Station. The Ground Station must also acquire carrier lock and synchronization to establish normal LDR mission operations.

(2) MDR User. Functional flow diagrams for MDR User acquisition operations are shown in Figure 2-44, Sheets 1, 2 and 3. There are significant differences and additions in the MDR case. Since it is assumed that we are acquiring the MDR User for the first time, the directional MDR antennas are not oriented and commands cannot be transmitted or received. Hence, the same flow of operations is first exercised as in the LDR User case, and shown in Sheet 1, for activating the assigned frequency and commanding the MDR and VHF transmitters to be on. After this is done and the return carrier and modulation are received at the Ground Station and both carrier and synchronization are acquired by the Ground Station, MDR antenna program instructions or commands can be transmitted, received and the antennas oriented. Thus, on Sheet 2, the Ground Station generates and transmits such antenna commands by Ku-band and the TDRS receives and processes these commands and activates an S- or Ku-band beacon. At the same time the Ground Station sends similar antenna commands via Ku-band to the User via the TDRS. The TDRS orients its MDR antenna to the User for autotrack mode operation and verifies it. The TDRS also transponds the User command to the User via UHF where it is received, processed and the User antenna oriented to the TDRS, and verified. With these operations accomplished, the MDR User now acquires the S-band/Ku-band beacon in an autotrack mode and transmits a

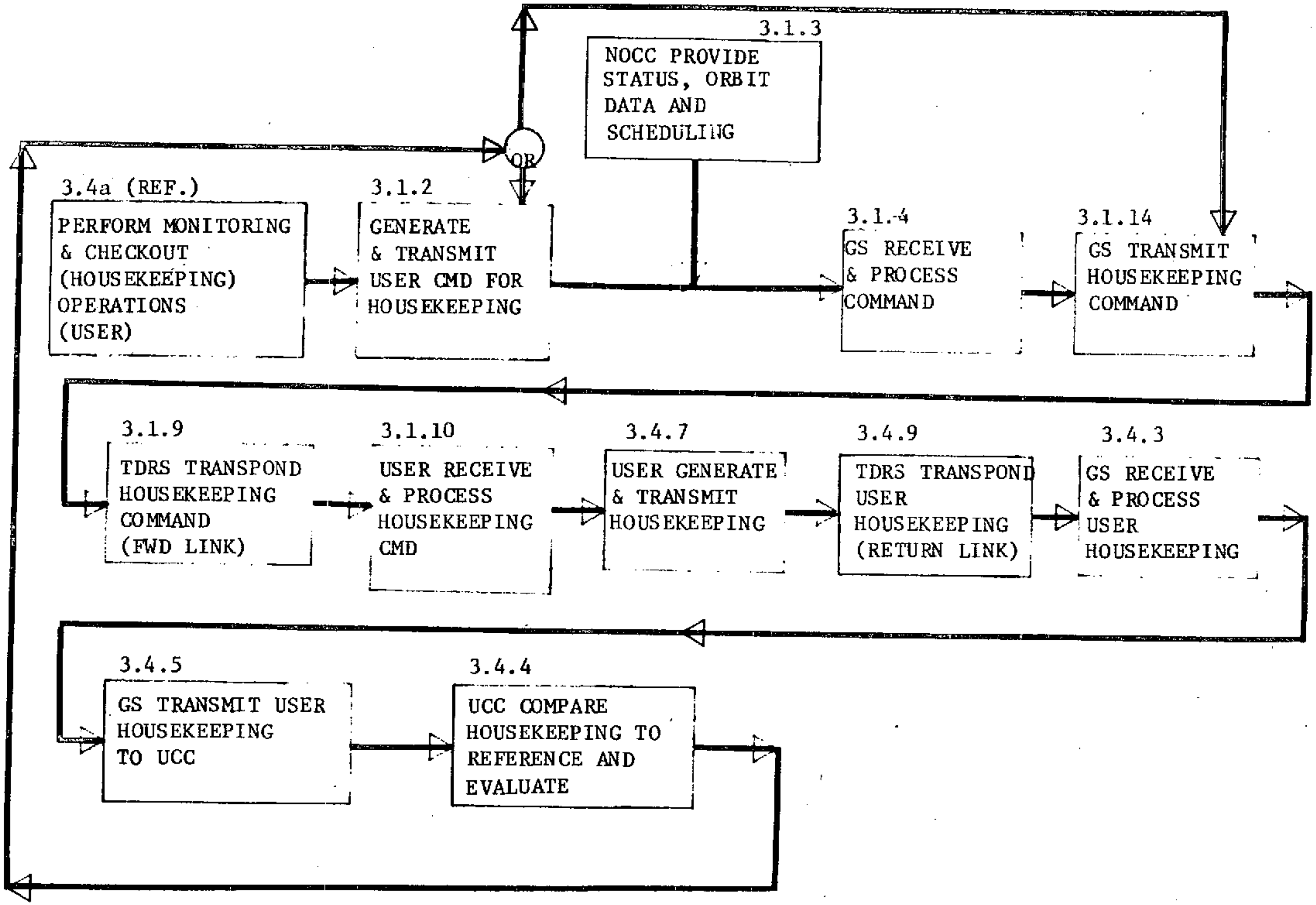
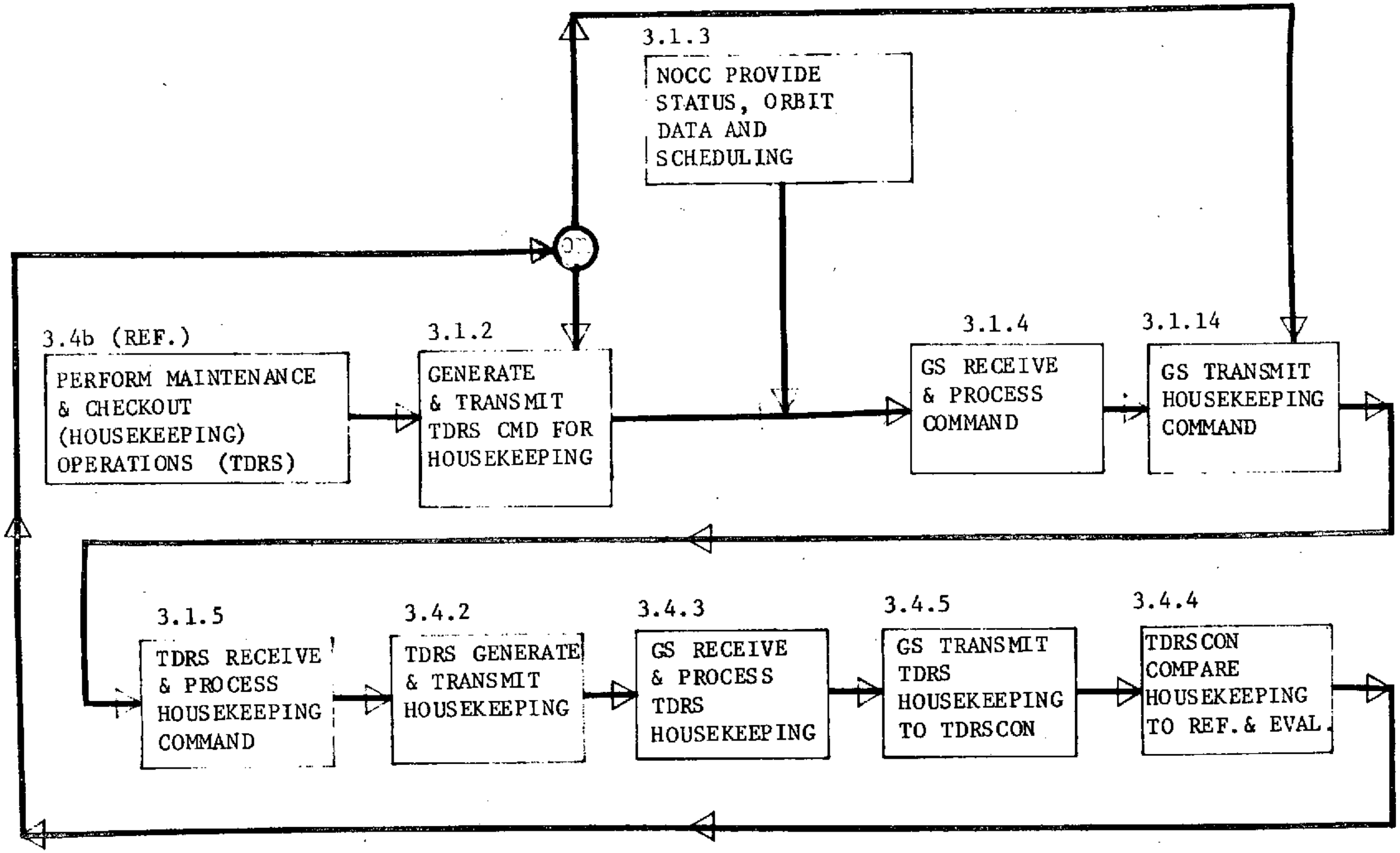


FIGURE 2-39
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.4a PERFORM MONITORING AND CHECKOUT (HOUSEKEEPING) OPERATIONS - USER



2-40
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.4b PERFORM MONITORING AND CHECKOUT (HOUSEKEEPING) OPERATIONS - TDRS

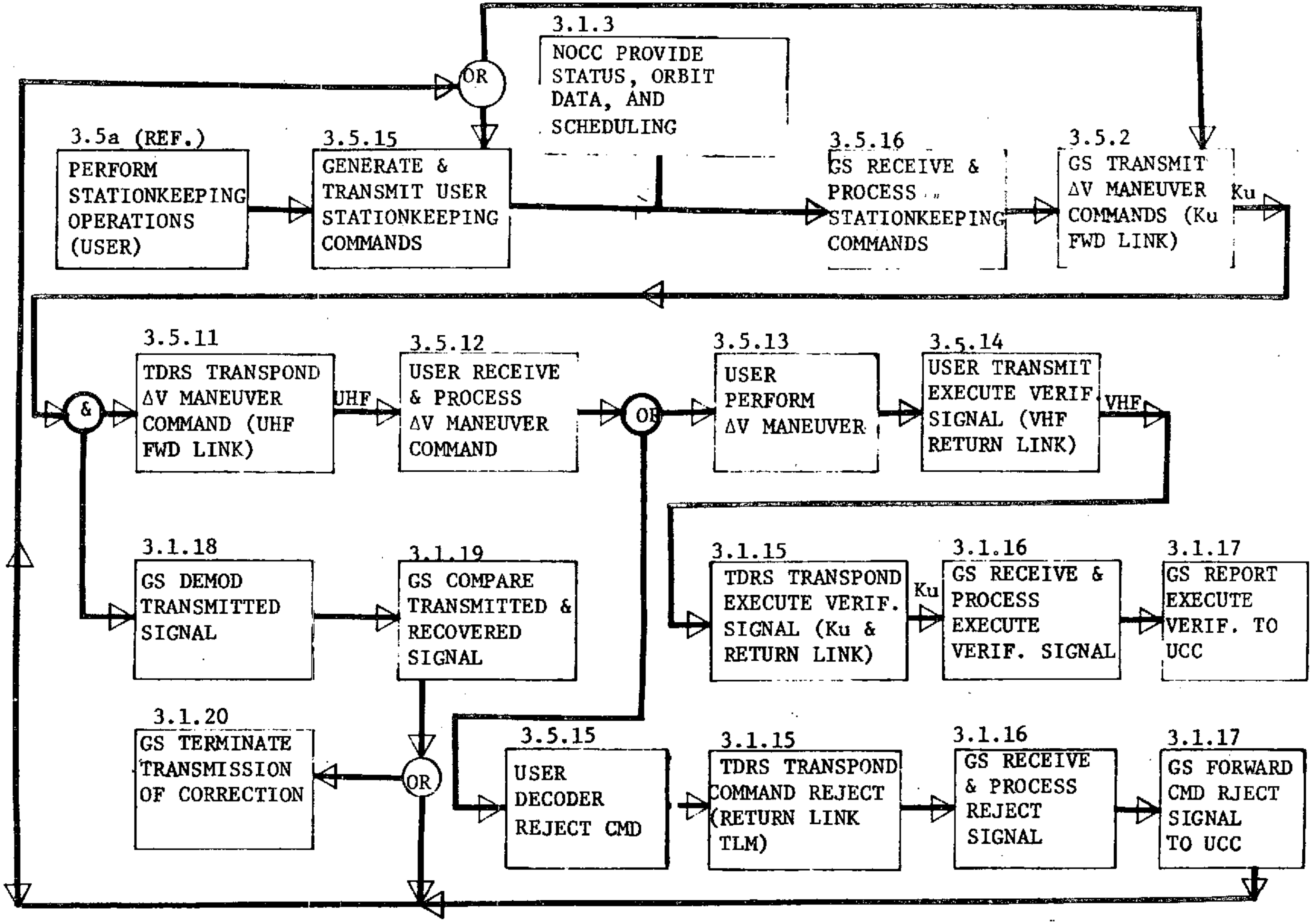


FIGURE 2-41 . SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.5a PERFORM STATIONKEEPING OPERATIONS - USER

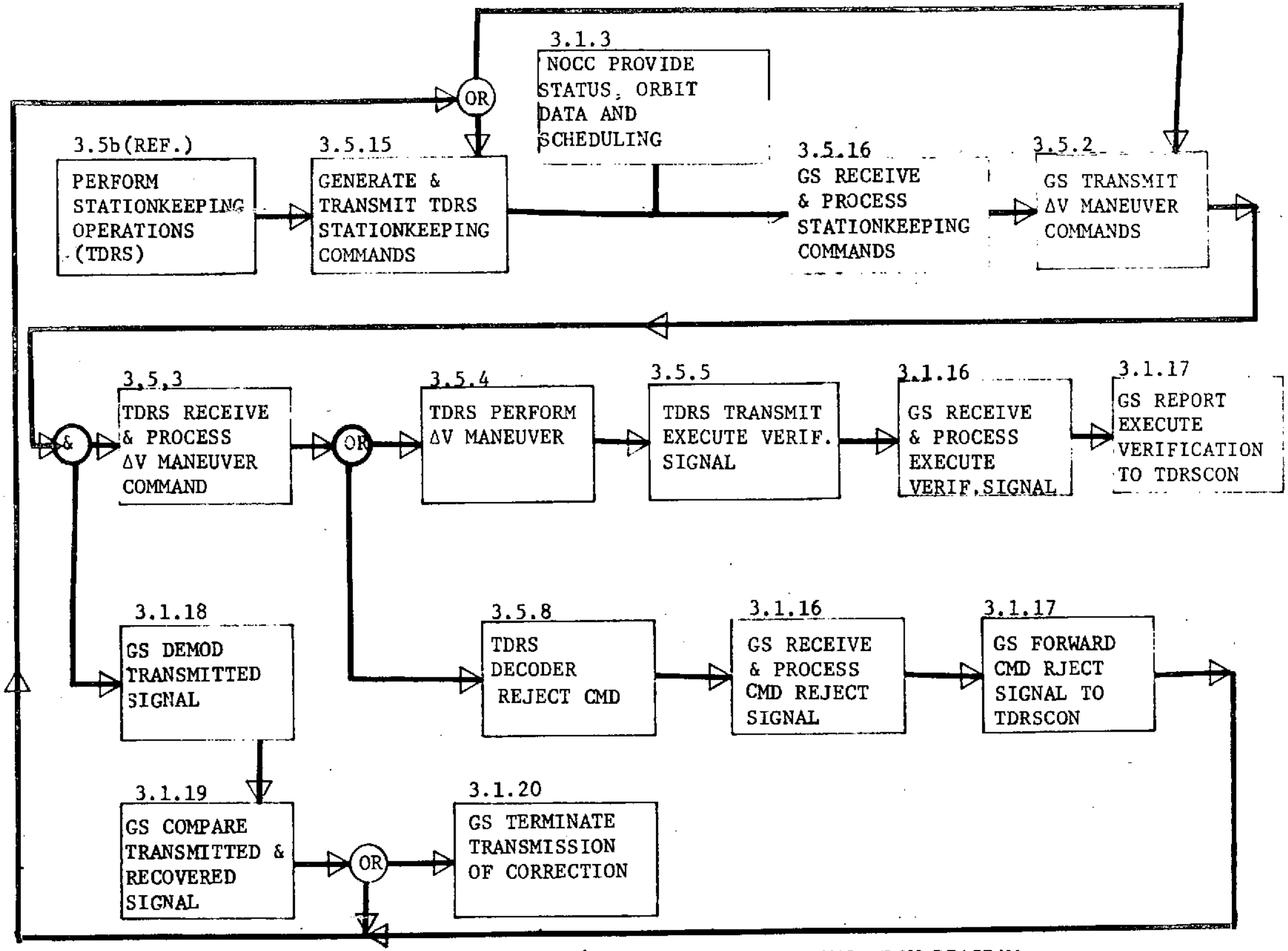


FIGURE 2-42 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.5b PERFORM STATIONKEEPING OPERATIONS - TDRS

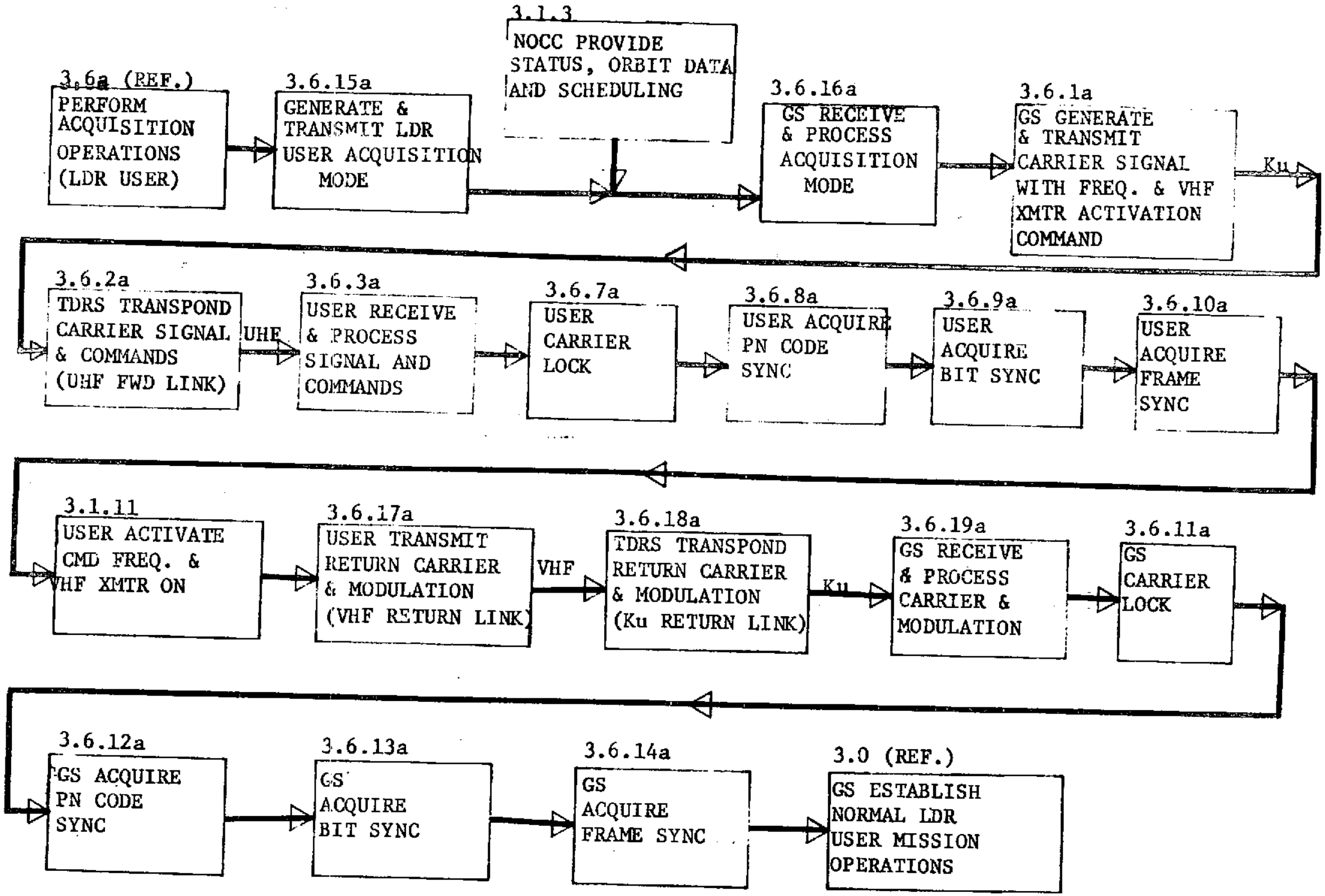


FIGURE 2-43 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.6a PERFORM ACQUISITION OPERATIONS-LDR USER

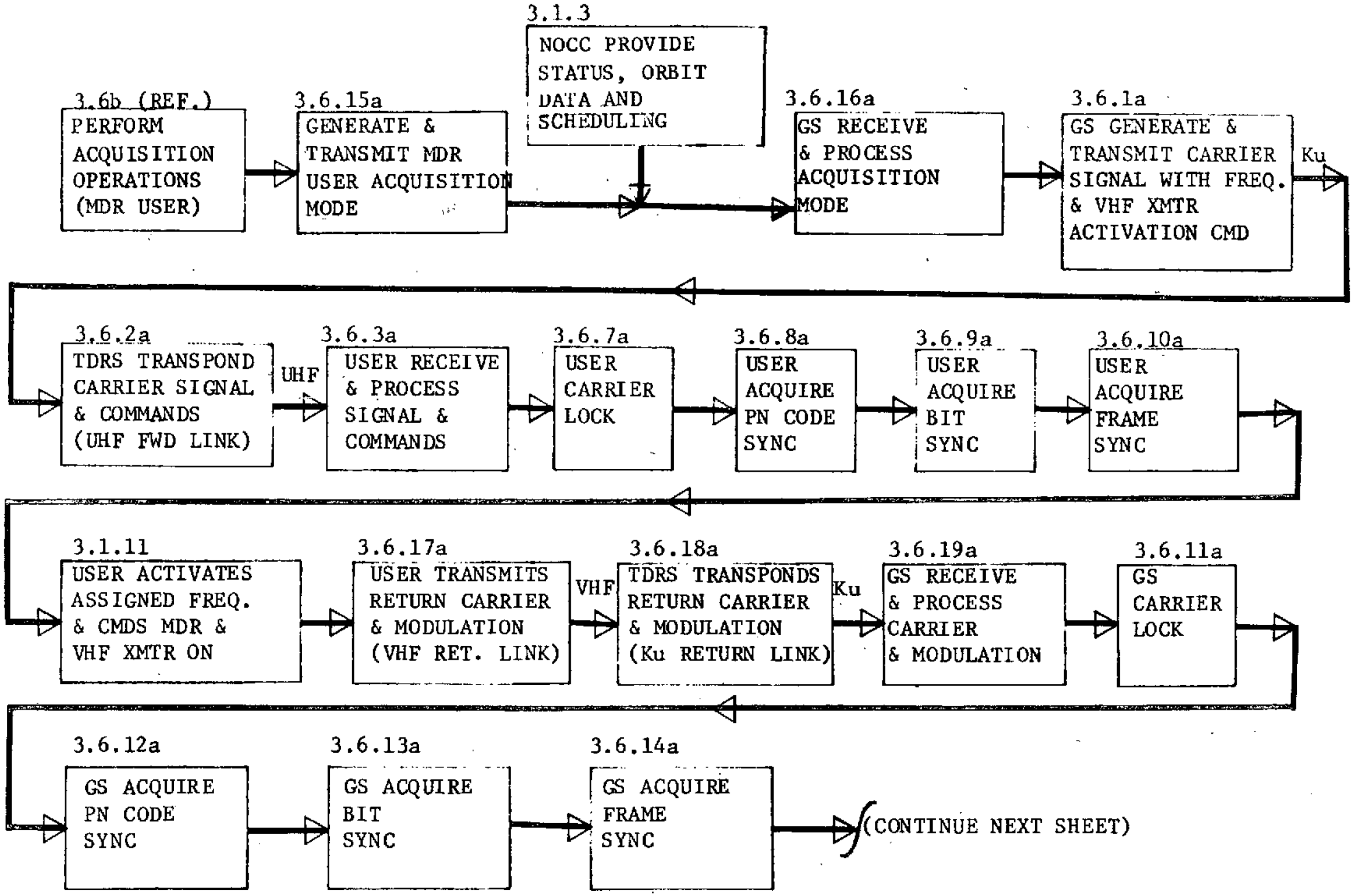


FIGURE 2-44
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.6b PERFORM ACQUISITION OPERATIONS--MDR USER

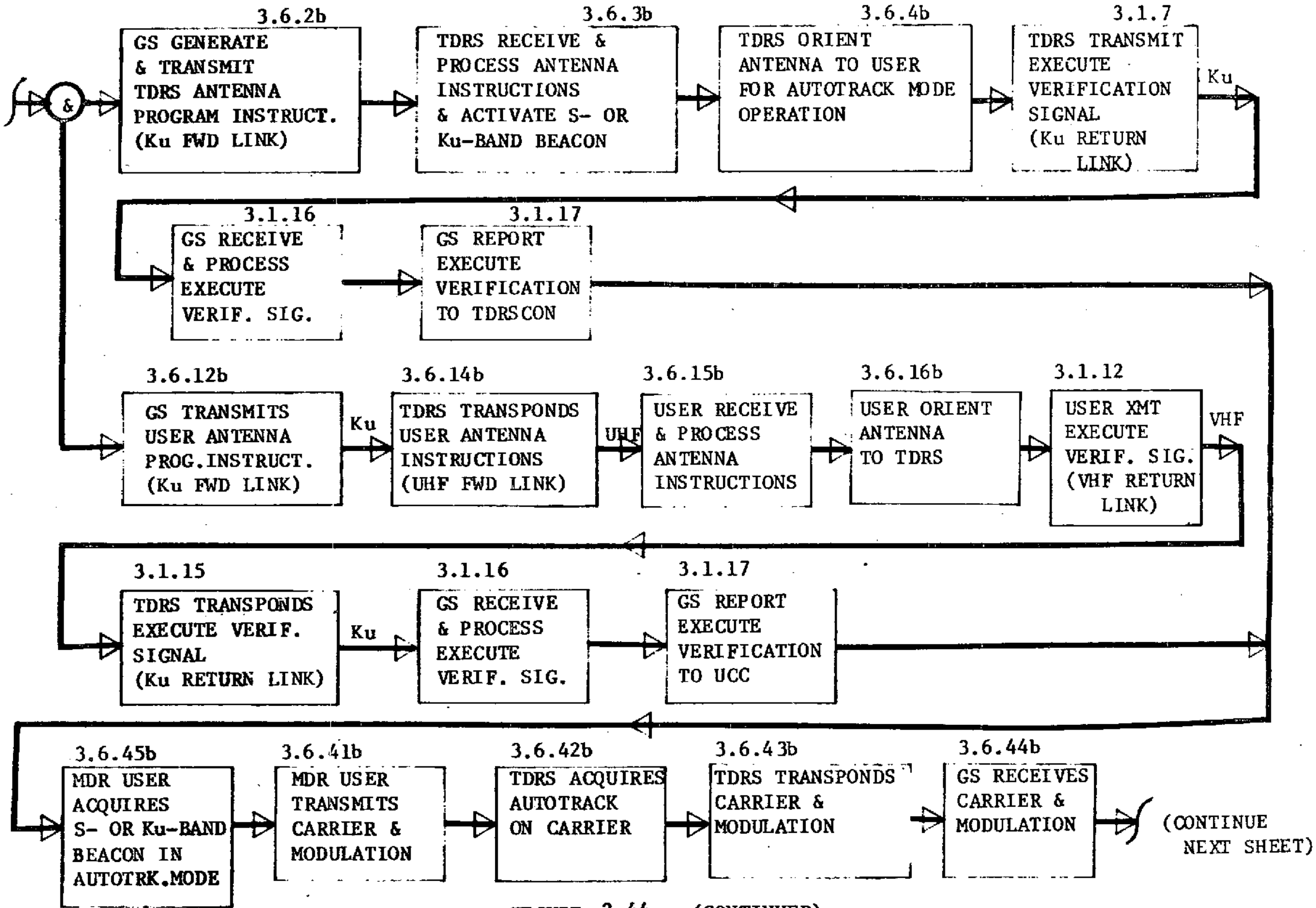


FIGURE 2-44 (CONTINUED)
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.6b PERFORM ACQUISITION OPERATIONS - MDR USER

(SHEET 2)

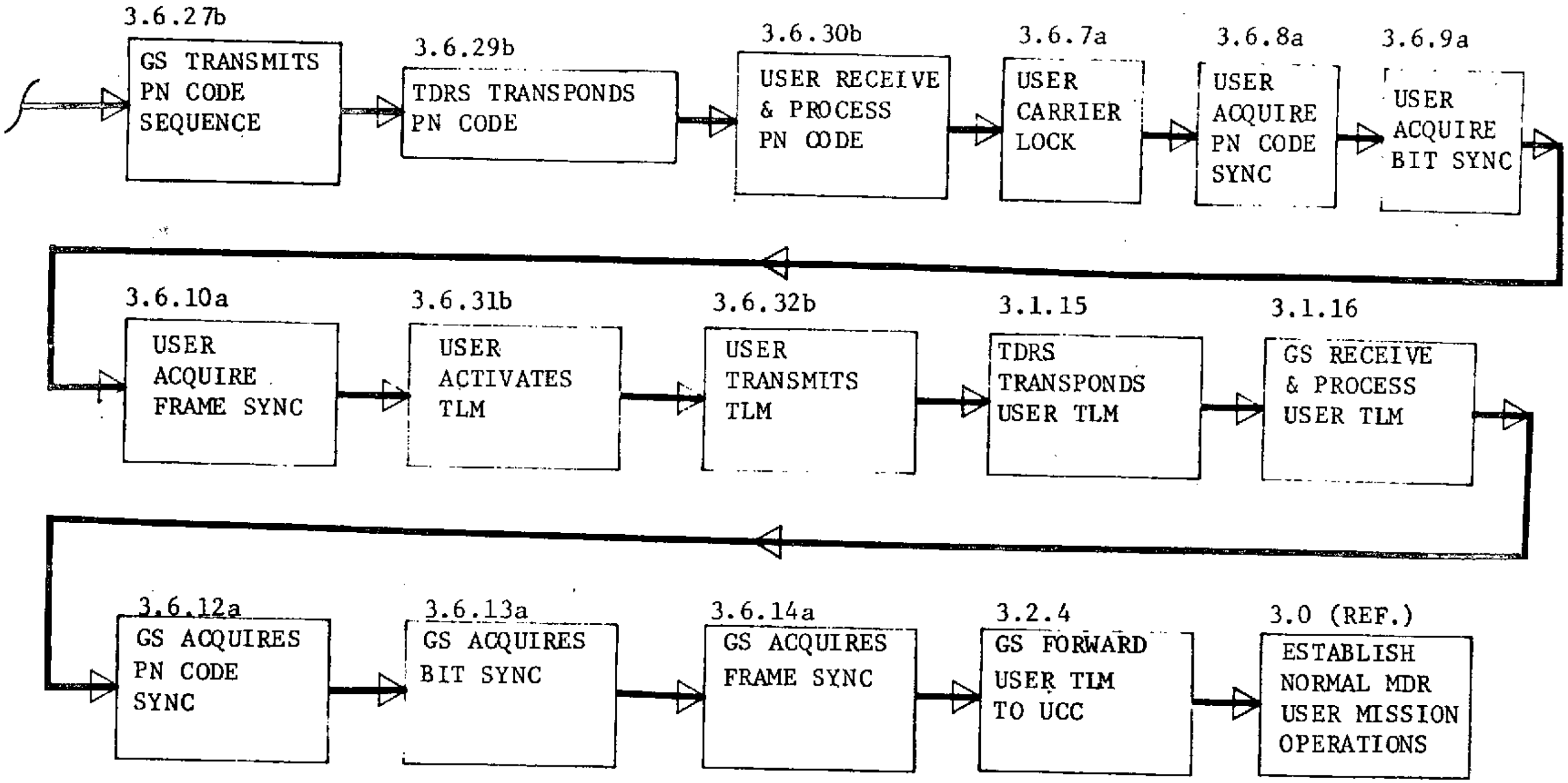


FIGURE 2-44 (CONTINUED)
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.6b PERFORM ACQUISITION OPERATIONS - MDR USER

(SHEET 3)

carrier with modulation, enabling the TDRS to acquire autotrack on the carrier. TDRS transponds this carrier and modulation to the Ground Station.

Now the Ground Station is ready to transmit a PN code sequence (Sheet 3), by the normal links. TDRS transponds the PN code, User receives and processes it, then User acquires carrier lock and synchronization before activating and transmitting telemetry data to the ground. After the Ground Station receives the telemetry and processes it, it acquires synchronization before transmitting the data to the User Control Center and establishing normal MDR User mission operations.

Handover Operations. (1) LDR User. The functional flow diagram for LDR User handover operations is shown in Figure 2-45. After the UCC generates, computes and develops an LDR User handover mode, it transmits it to the Ground Station for processing and transmission into space. The Ground Station generates and transmits a carrier signal with the required frequency switching command (from TDRS No. 1 frequency to TDRS No. 2 frequency) via the Ku-band forward link to TDRS No. 1 (with which the LDR User is currently linked). TDRS No. 1 transponds the carrier signal and frequency switching command to the User where it is received and processed. The User then switches from the TDRS No. 1 frequency to the TDRS No. 2 frequency and transmits by VHF return link a telemetry signal on the TDRS No. 2 frequency. This is transponded by the TDRS to the Ground Station where it is processed and the User telemetry is forwarded to the UCC. Thereafter normal LDR User mission operations continue through TDRS No. 2.

(2) MDR User. Diagrams for MDR User handover operations are shown in Figure 2-46, Sheets 1 and 2. Starting in the same way, there are some differences and additions due to the pointing of the MDR antennas. The functional flow contains similar operations as for the MDR User acquisition. The Ground Station, after receiving and processing the handover mode from the UCC, generates and transmits both TDRS No. 2 and User antenna commands via the Ku-band forward link. TDRS No. 2 receives and processes its antenna command and activates the S- or Ku-band beacon, then orients the antenna to the User for autotrack mode operation and verifies. TDRS No. 1 receives and transponds the User antenna commands by UHF forward link to the User where it is received and processed and the User antenna oriented to TDRS No. 2 and verified. After both sequences are completed and verified, the MDR User acquires the beacon in autotrack and transmits a carrier with modulation. TDRS No. 2 acquires autotrack on the carrier and transponds the carrier with modulation to the ground. The Ground Station then transmits a PN code sequence to TDRS No. 2 where it is transponded to the User and processed. The User acquires carrier lock and synchronization and activates telemetry for transmission to the ground. TDRS No. 2 transponds the User telemetry to the Ground Station where it is processed and synchronization acquired. The Ground Station forwards the User telemetry to the UCC and establishes normal MDR User mission operations through TDRS No. 2.

Eclipse Operations. TDRS eclipse operations are shown in Figure 2-47. Much of these operations can be preprogrammed for the relatively short periods of eclipse, provided overrides are available to TDRSCON as required to adjust to special conditions. An eclipse program plan is computed and developed

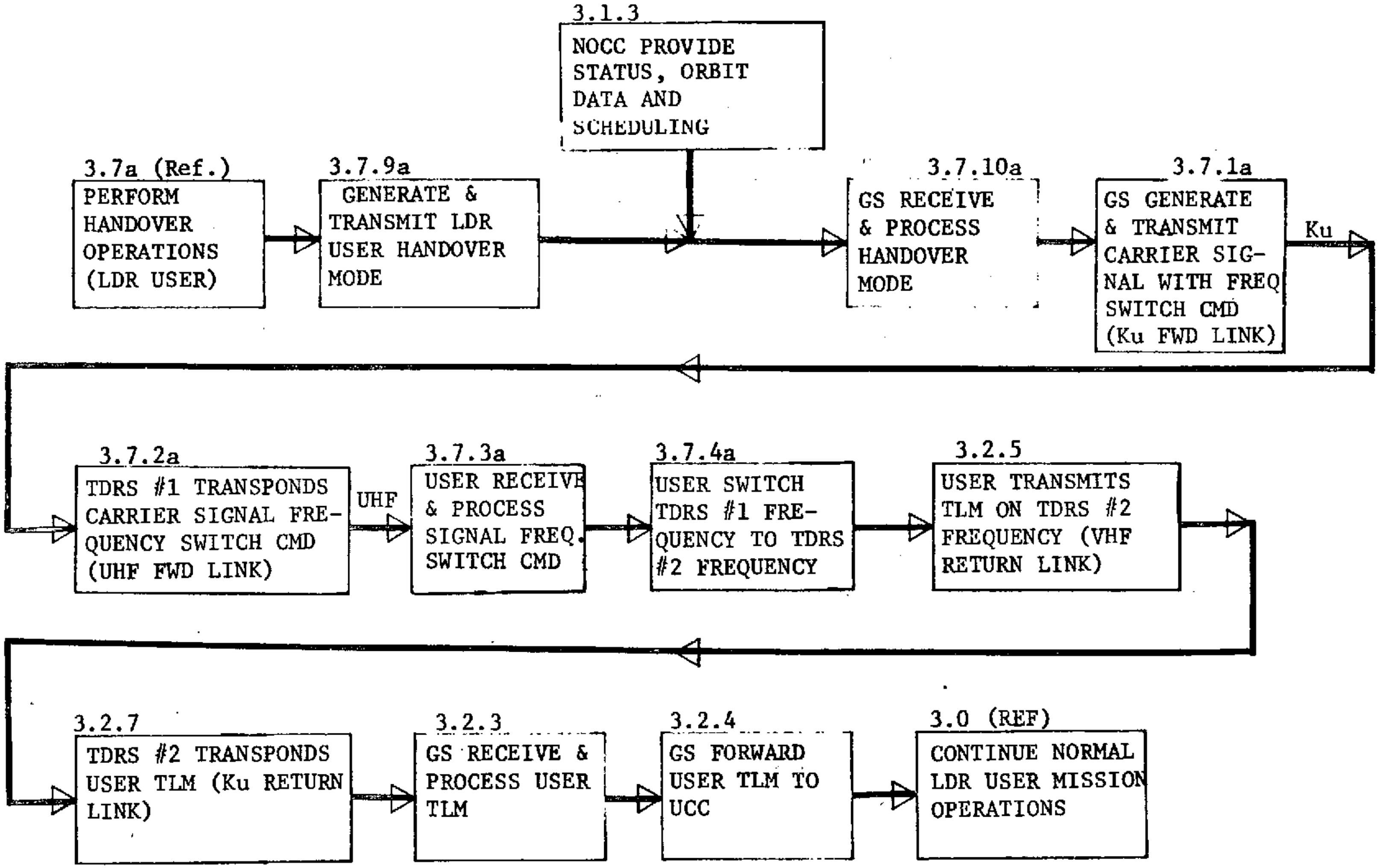


FIGURE 2-45 . SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.7a PERFORM HANDOVER OPERATIONS LDR USER

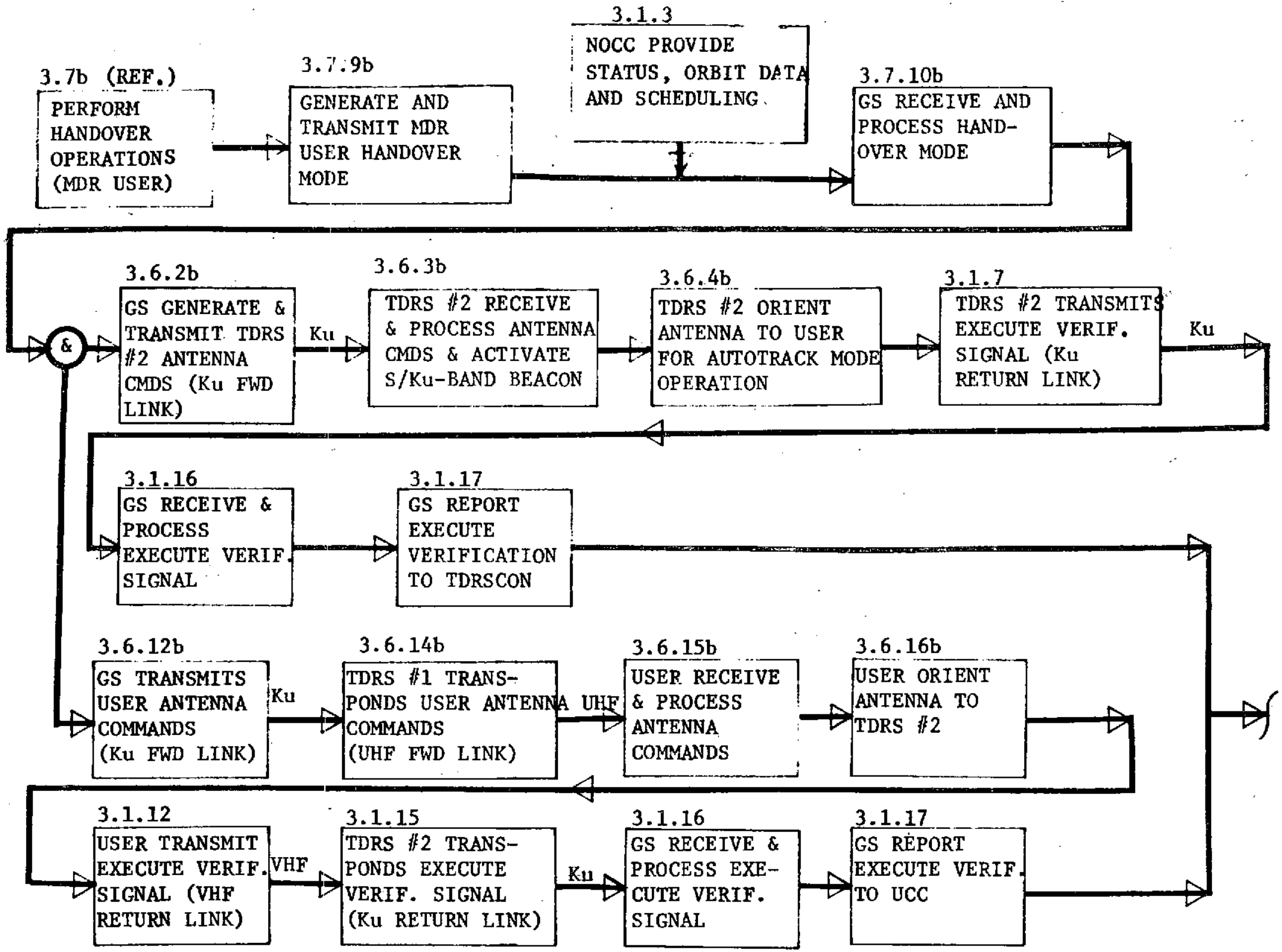


FIGURE 2-46 . SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.7b PERFORM HANDOVER OPERATIONS - MDR USER

(SHEET 1)

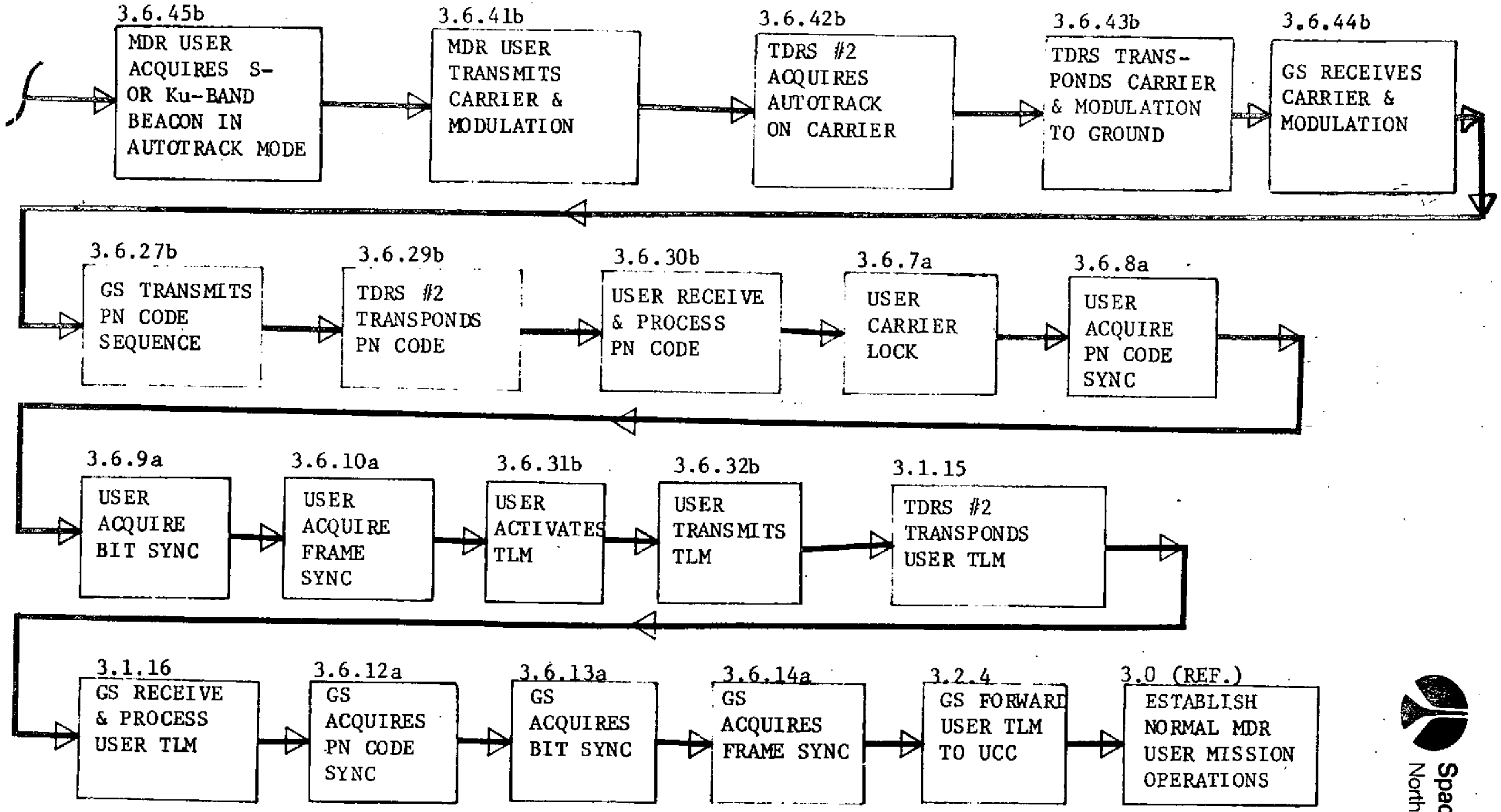


FIGURE 2-46 (CONTINUED)
SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.7b PERFORM HANDOVER OPERATIONS - MDR USER

(SHEET 2)

and stored for repeated use in recurring eclipse periods. The TDRS senses the eclipse status and activates the batteries and deactivates or discontinues selected or unusable equipments and operations. As a minimum, the TDRS will have sufficient power from the batteries to continue the TT&C and housekeeping operations and maintain the frequency source, as well as to continue all return links and some level of MDR and/or LDR forward link operations.

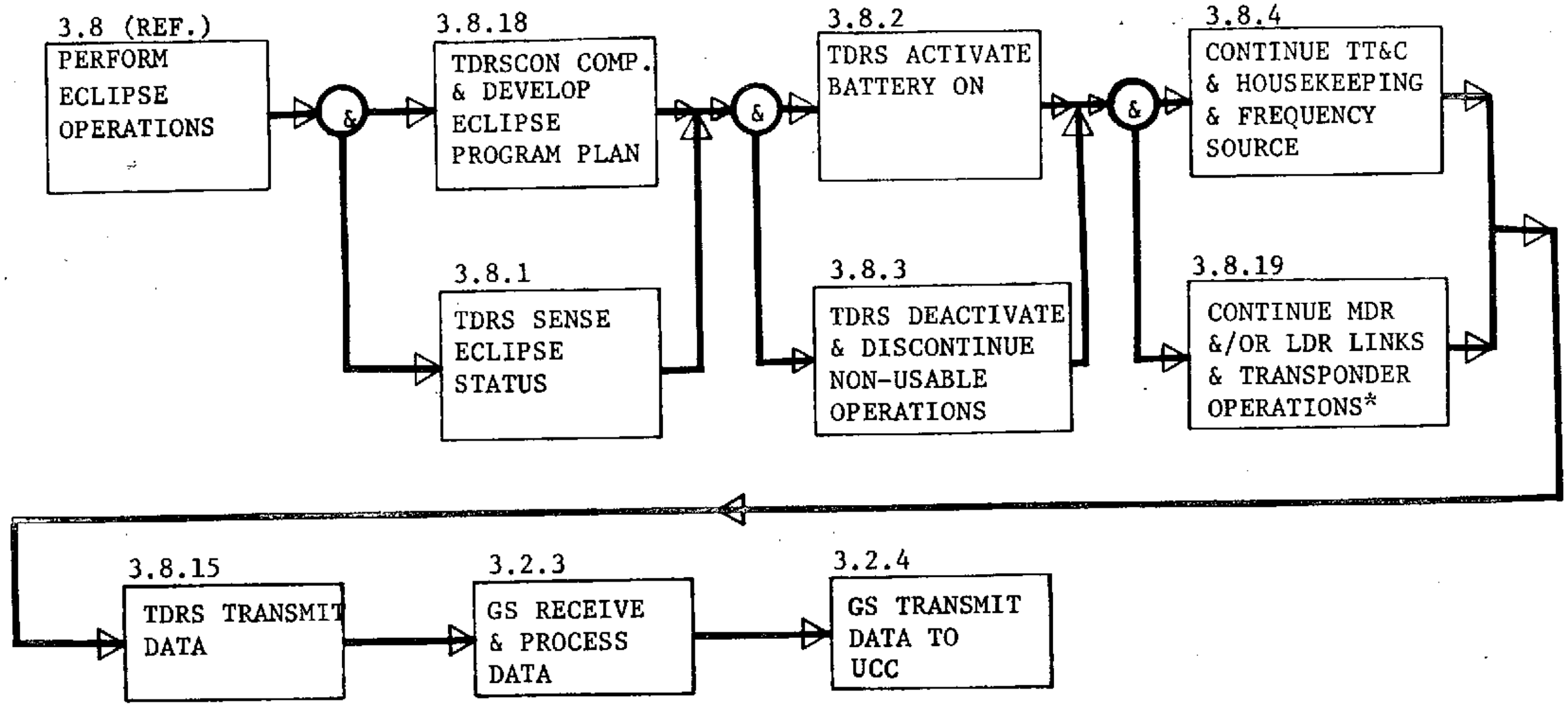
Station Transfer Operations. TDRS station transfer operations are shown in Figure 2-48. TDRSCON determines the spacecraft status by telemetry and tracking and generates and transmits a computed and developed station transfer mode. After receiving and processing this mode at the Ground Station, the first delta V maneuver command is transmitted to the spare spacecraft. At the same time the Ground Station verifies its operation by demodulating the transmitted signal and comparing it and the recovered signal for correctness. It may then terminate the transmission or retransmit the signal or the TDRSCON may regenerate and retransmit the mode. The delta V maneuver command is received by the spare and the maneuver performed and verified or the command decoder status requested. At the same time the spare is tracked to the vicinity of the desired station and at an appropriate time the Ground Station transmits a second delta V maneuver command to stop the spacecraft.

2.2.3.6 Third/Fourth Level Functional Flow Diagrams

Third/fourth level functional flow diagrams were developed for most of the operations in the preceding set of second/third level functional flow diagrams and are shown in Figures 2-49 through 2-81. It is at this level that the full implications of a TDRS System Concept that meets the objectives of real-time system operation with minimum impact on existing and planned facilities and organizations are realized. At the same time, consideration is given, by means of alternative operational sequences, to those cases where more routine operations are either the only kinds available (to small Users), or are desired and executed because they are not time-sensitive (by large and small Users). The functional flow diagrams are readily interpretable for their meaning and implications and not individually discussed. However, some significant features among them are singled out for special attention.

Figure 2-50 shows the diagram for the generation and transmission of commands. For real-time operation, the UCC or TDRSCON determines the command requirements and priority status, provides the spacecraft orbital parameters, and then encodes, buffers, and routes the command for transmission directly to the Ground Station via NASCOM (and Modem operation). A more routine procedure would be to send a hard copy command, schedule and format to the Ground Station.

Figure 2-52 shows the diagram for the Ground Station receiving and processing a real-time command or a command request. For the real-time sequence, the command is received by a command processor, where multiplexing and priority routing, data encoding and high speed modem operations are performed before transmission to the Ground Station as a command signal. Command requests can be delivered by mail, TTY or telephone. The first two



* EXTENT OF THE LDR AND MDR OPERATION WILL DEPEND ON THE POWER LEVELS AVAILABLE FOR EACH OPERATION.

FIGURE 2-47 SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.8 PERFORM ECLIPSE OPERATIONS

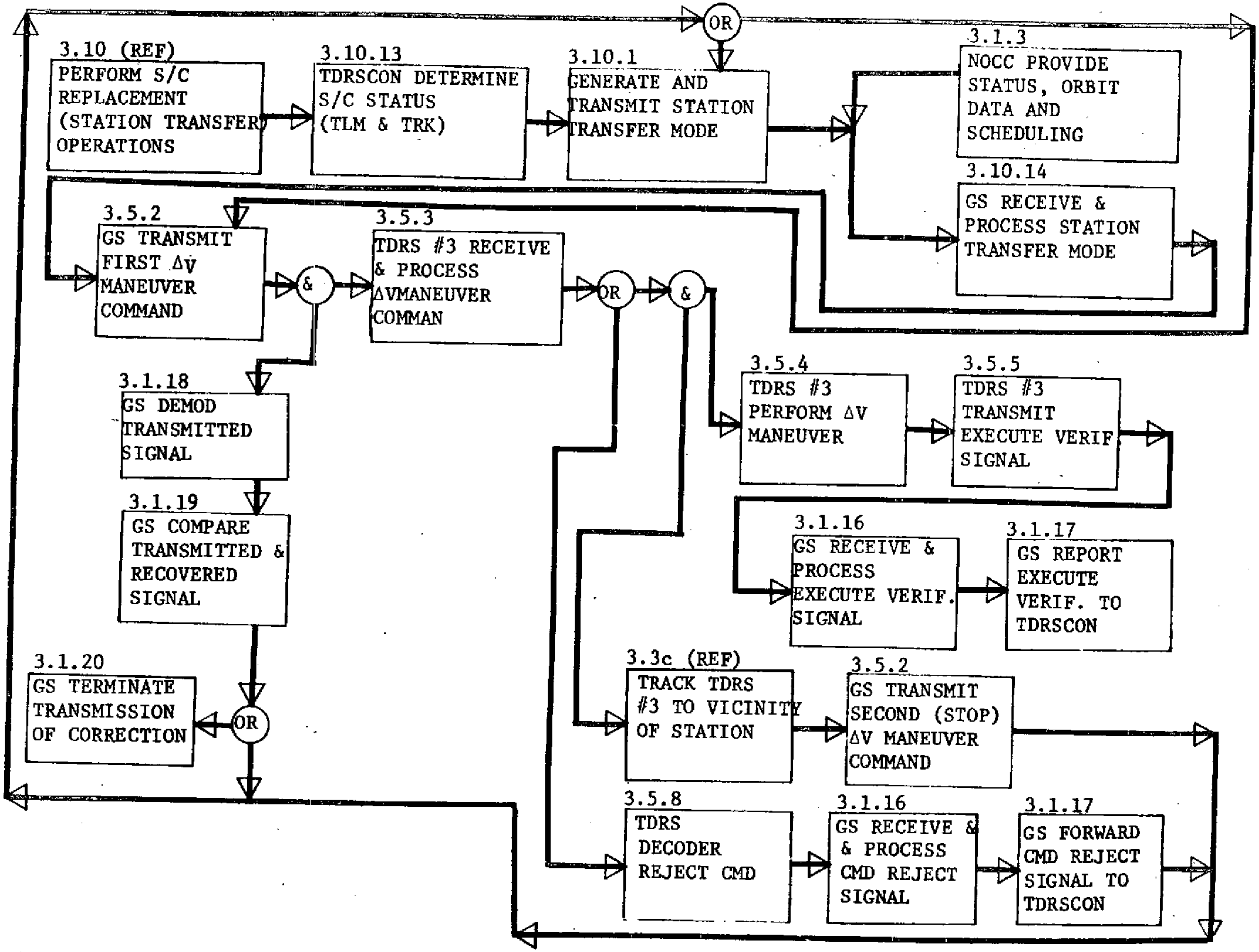


FIGURE 2-48. SECOND/THIRD LEVEL FUNCTIONAL FLOW DIAGRAM
3.10 PERFORM SPACECRAFT REPLACEMENT (STATION TRANSFER) OPERATIONS

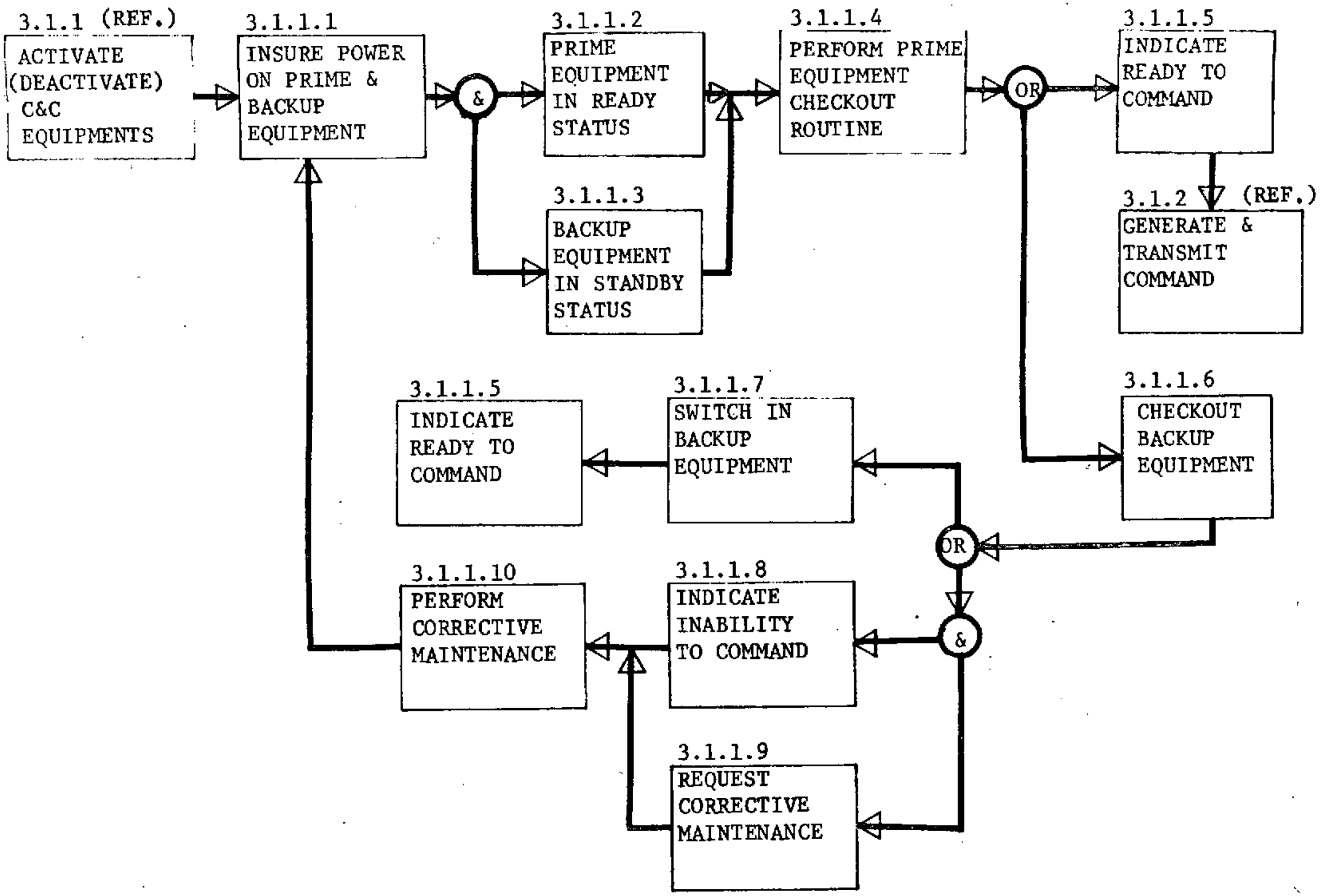


FIGURE 2-49 . THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.1 ACTIVATE (DEACTIVATE) C&C EQUIPMENTS

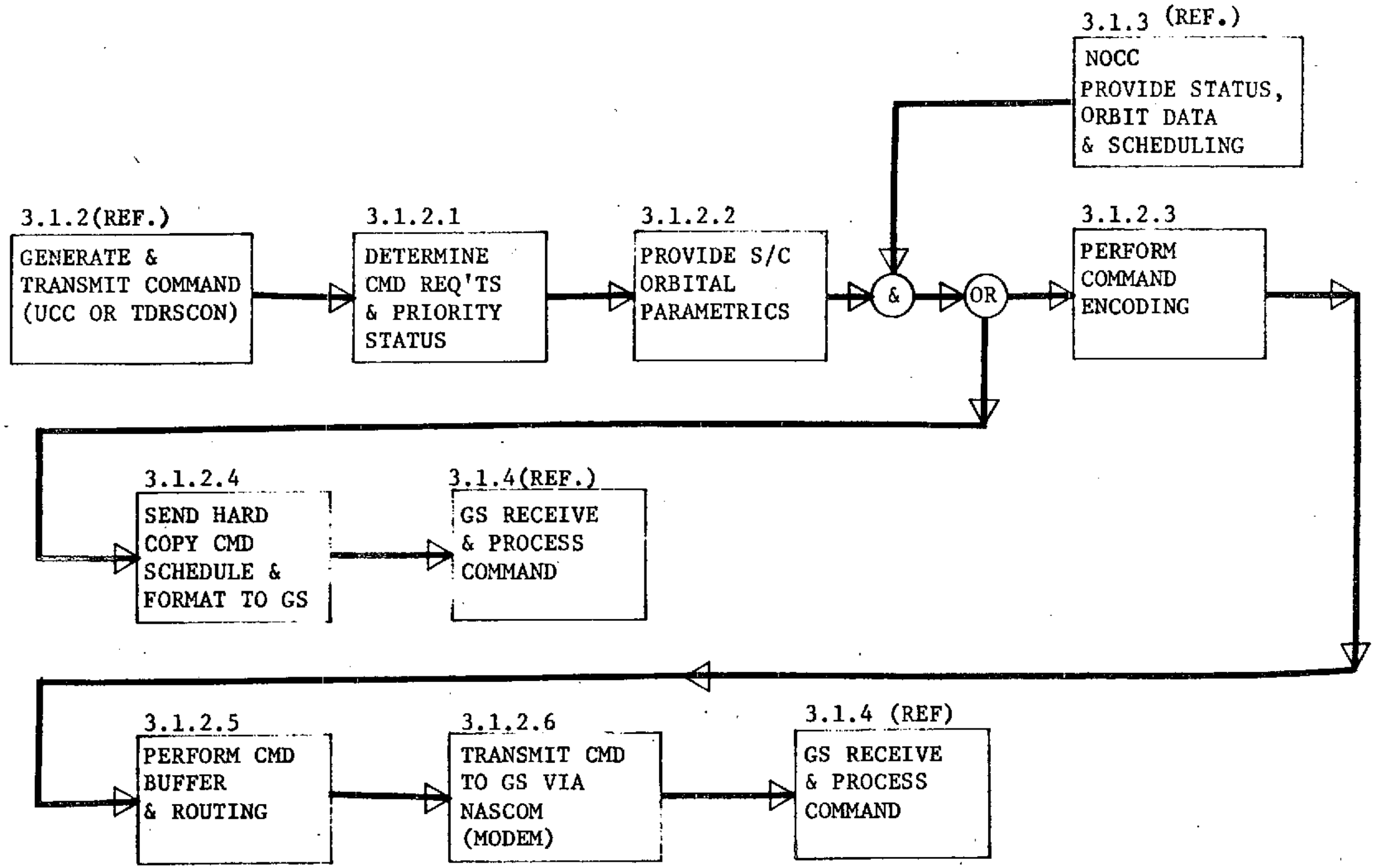


FIGURE 2-5Q THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.2 GENERATE & TRANSMIT COMMAND (UCC OR TDRSCON)

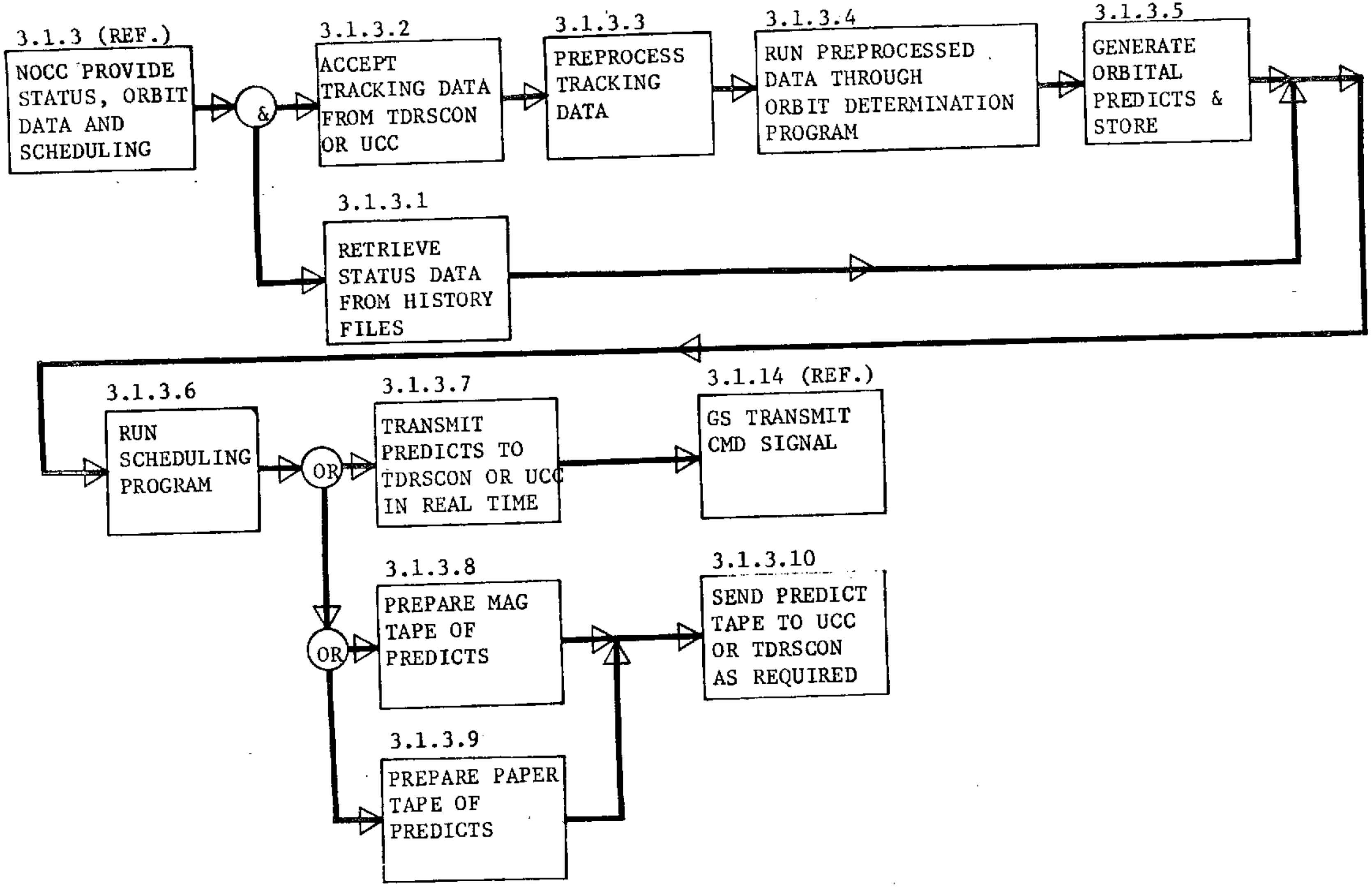


FIGURE 2-51
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.3 GS PROVIDE STATUS, ORBIT DATA, AND SCHEDULING

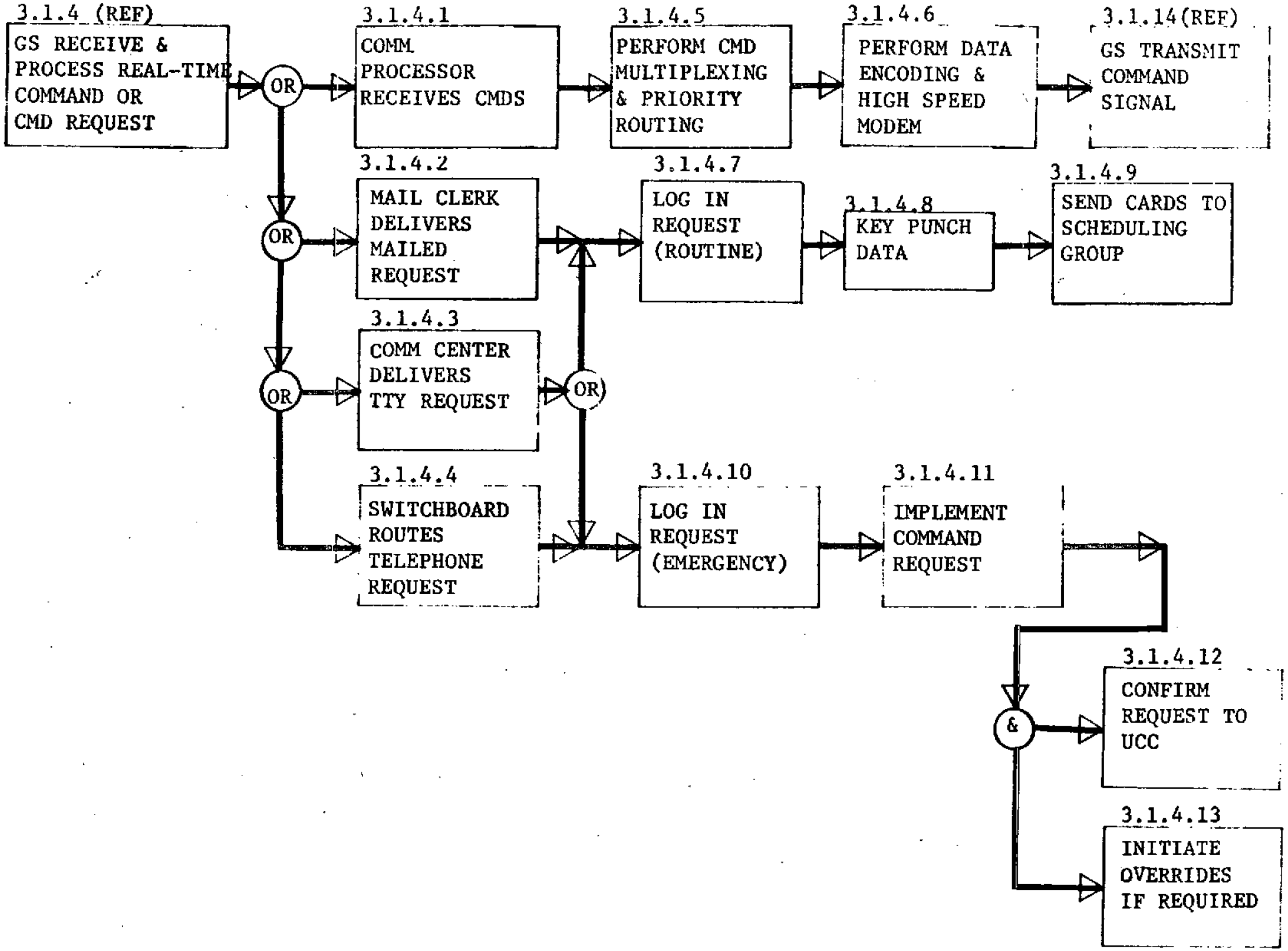


FIGURE 2-52. THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.4 GS RECEIVE & PROCESS REAL-TIME CMD OR CMD REQUEST

are quite routine and handled that way. The telephoned command request can be an emergency and if necessary it receives emergency handling and implementation.

Figure 2-53 shows the **Ground Station transmission of a command signal.** In the real-time case the command or command request is received at the Ground Station in real-time, undergoes decoding and high speed modem operation, buffering and routing before a command data code is generated and a PN code applied for the selected modulator, transmitter, and antenna. More routine procedures involve manual and computer construction of binary commands, preparing and loading tapes before the PN code is applied.

Figure 2-67 shows the **Ground Station receiving and processing User data.** The Ground Station first acquires carrier lock and PN code and bit synchronization. It then removes error control code and either (a) requires word and frame synchronization before processing the data and transmitting the processed data to the UCC or (b) it records and transmits the raw unde• commutated data to the UCC.

Figure 2-68 shows the Ground Station transmitting these data to the UCC. After receiving User data the Ground Station processes and multiplexes the data before transmitting it via NASCOM (with Modem operation) to the UCC. The UCC acquires bit synchronization before demultiplexing the data. It may then acquire word and frame synchronization on processed data before display, or acquire the word and frame synchronization on unprocessed data before processing for display.

Figure 2-70 shows the TDRS transponding a ranging code return signal. The TDRS may receive the signal on Ku-band, on S-band, or on VHF. In the Ku-band case, the TDRS acquires coherency of the return to forward links and then translates the PN code to another Ku-band frequency. It also converts the Ku-band signal to S-band, reradiates the PN code so that two STDN tracking stations can receive it, acquire PN code synchronization and retransmit a PN code signal at S-band to the TDRS, where it is converted back to Ku-band. In the S-band case, the TDRS simply translates the S-band to K-band. Also in the VHF case, the TDRS downconverts the VHF signal from each antenna to Ku-band. In each of these cases, the TDRS modulates the Ku-band transmitter and radiates the signal on Ku-band to the Ground Station.

Figure 2-72 shows the Ground Station reporting tracking data to the Control Center. The real-time procedure is for the Ground Station to process and multiplex the data before transmitting to the UCC. The UCC then acquires bit synchronization and processes and demultiplexes the data before acquiring word and frame synchronization. It then decommutates data for the displays and inputting to the orbit determinating program. Routine procedures record the data on tape and ship the tapes to the UCC.

Figure 2-79 shows the generation and transmission of User or TDRS stationkeeping commands. The UCC or TDRSCON computes and develops delta V maneuver requirements and defines its magnitude and time of execution. It them computes the delta V burn time, determines the auxiliary propulsion

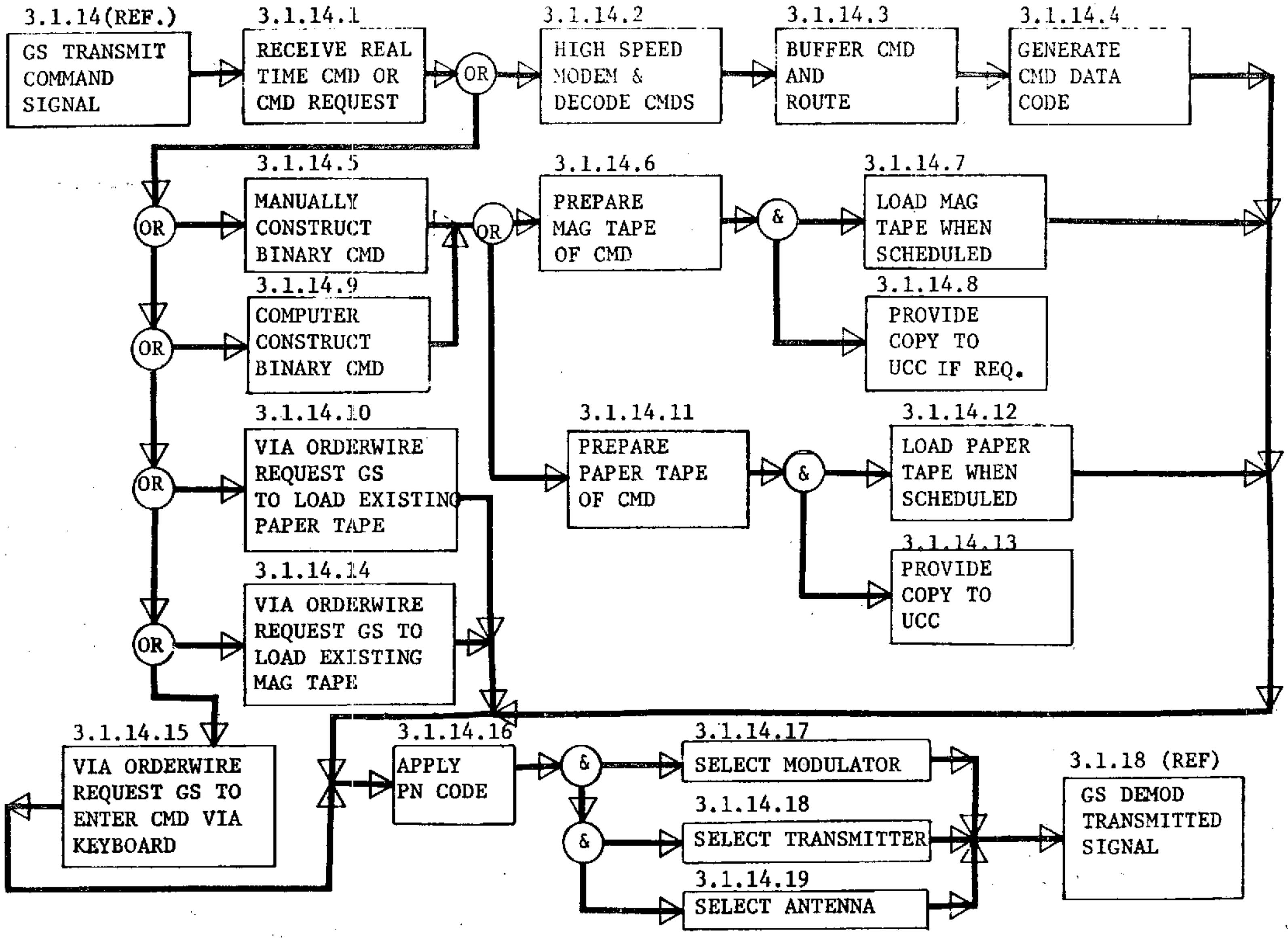


FIGURE 2-53. THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.14 GS TRANSMIT COMMAND SIGNAL

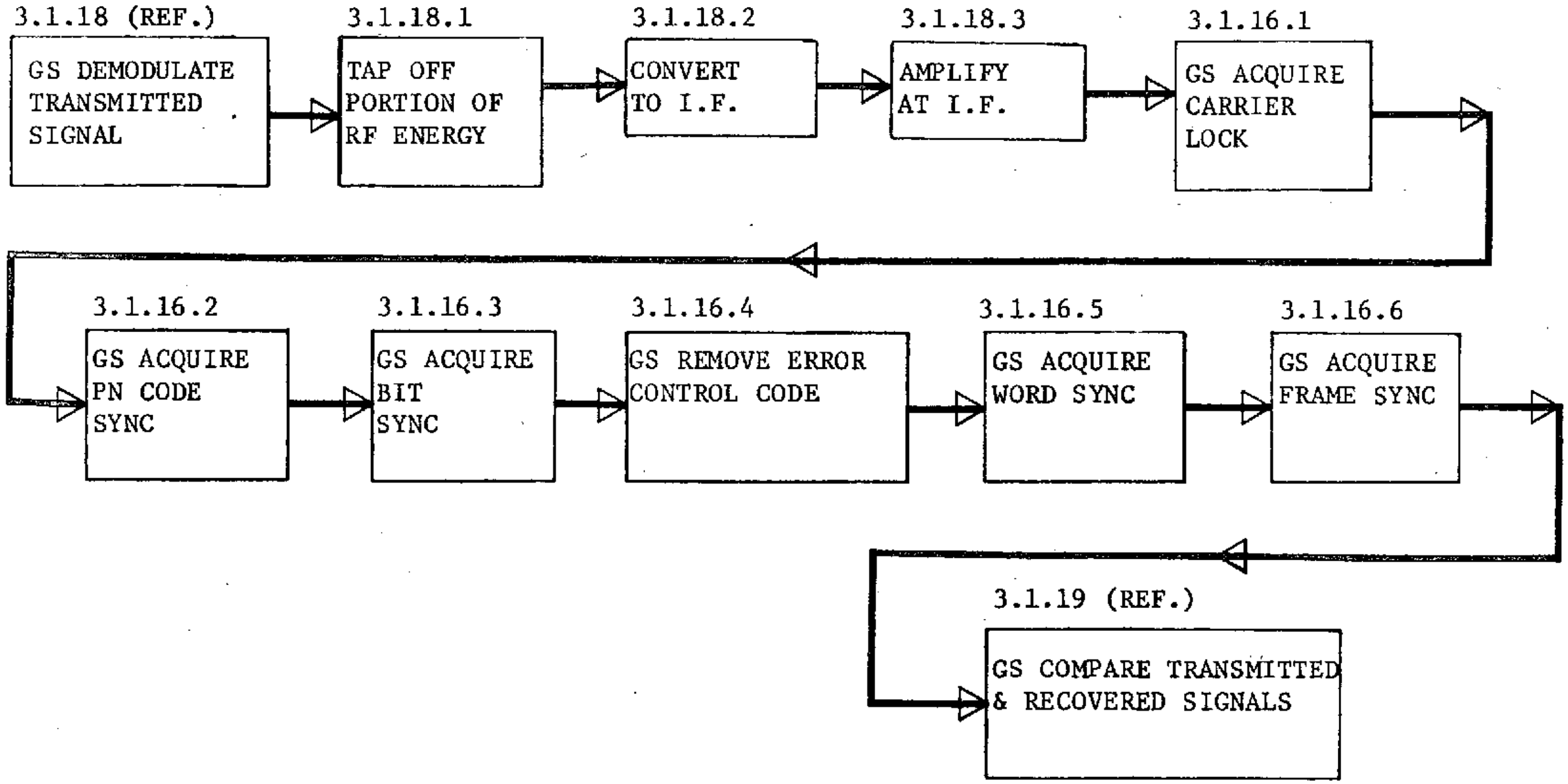


FIGURE 2-54
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.18 GS DEMODULATE TRANSMITTED SIGNAL

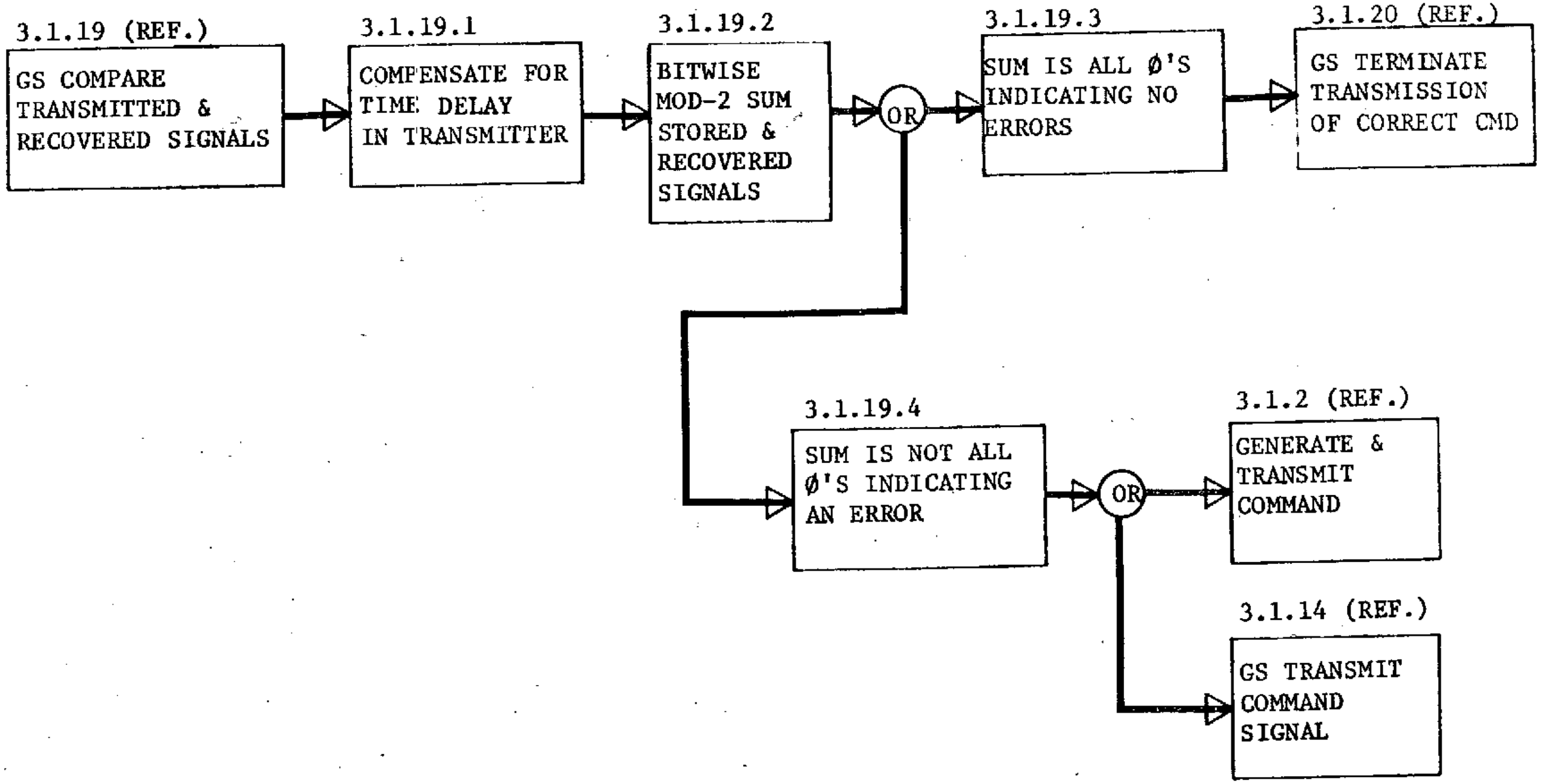


FIGURE 2-55
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.19 GS COMPARE TRANSMITTED AND RECOVERED SIGNALS

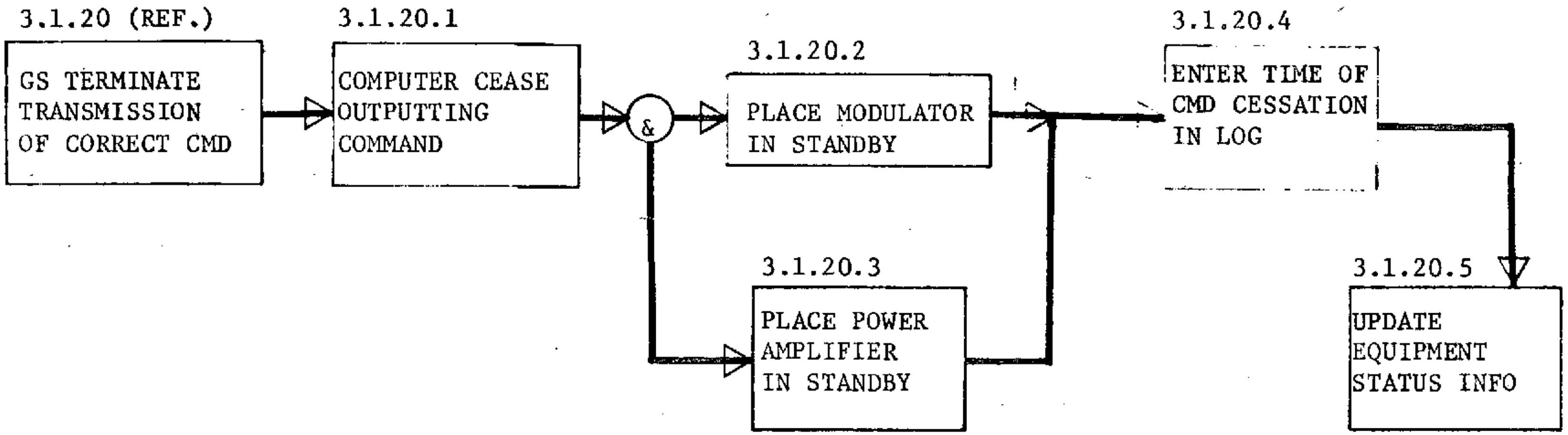


FIGURE 2-56
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.20 GS TERMINATE TRANSMISSION OF CORRECT COMMAND

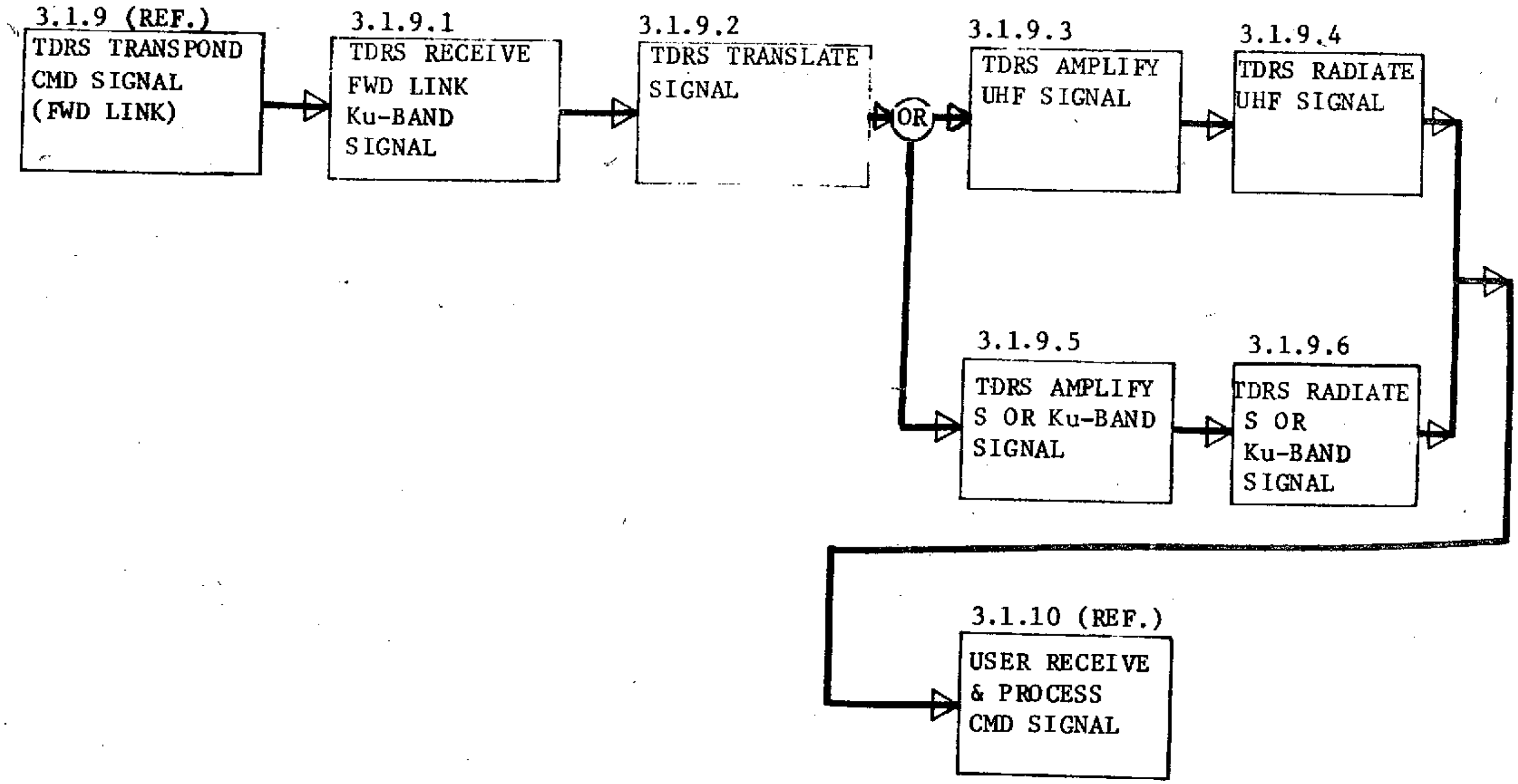


FIGURE 2-57
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.9 TDRS TRANSPOND COMMAND SIGNAL (FORWARD LINK)

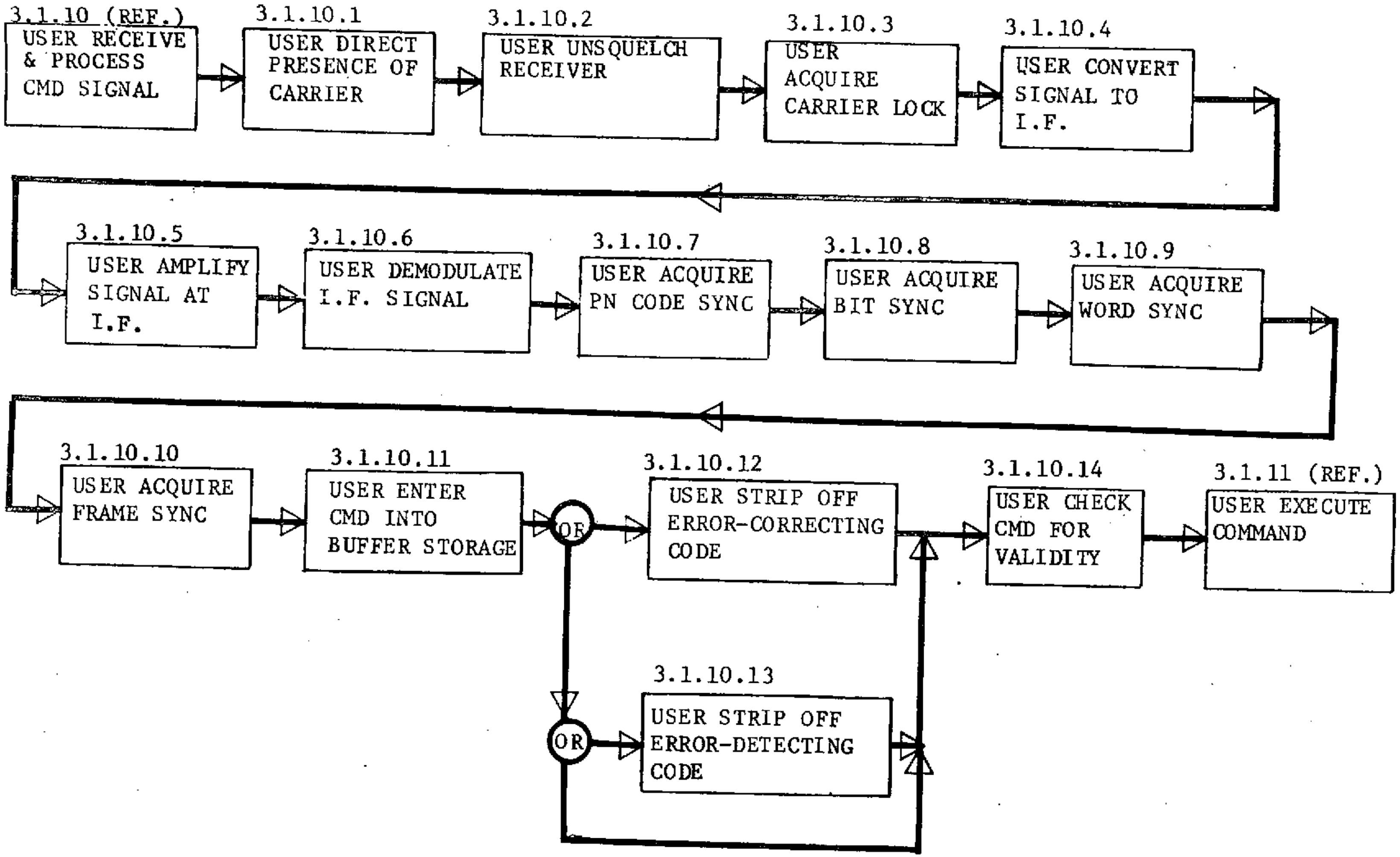


FIGURE 2-58
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.10 USER RECEIVER AND PROCESS COMMAND SIGNAL

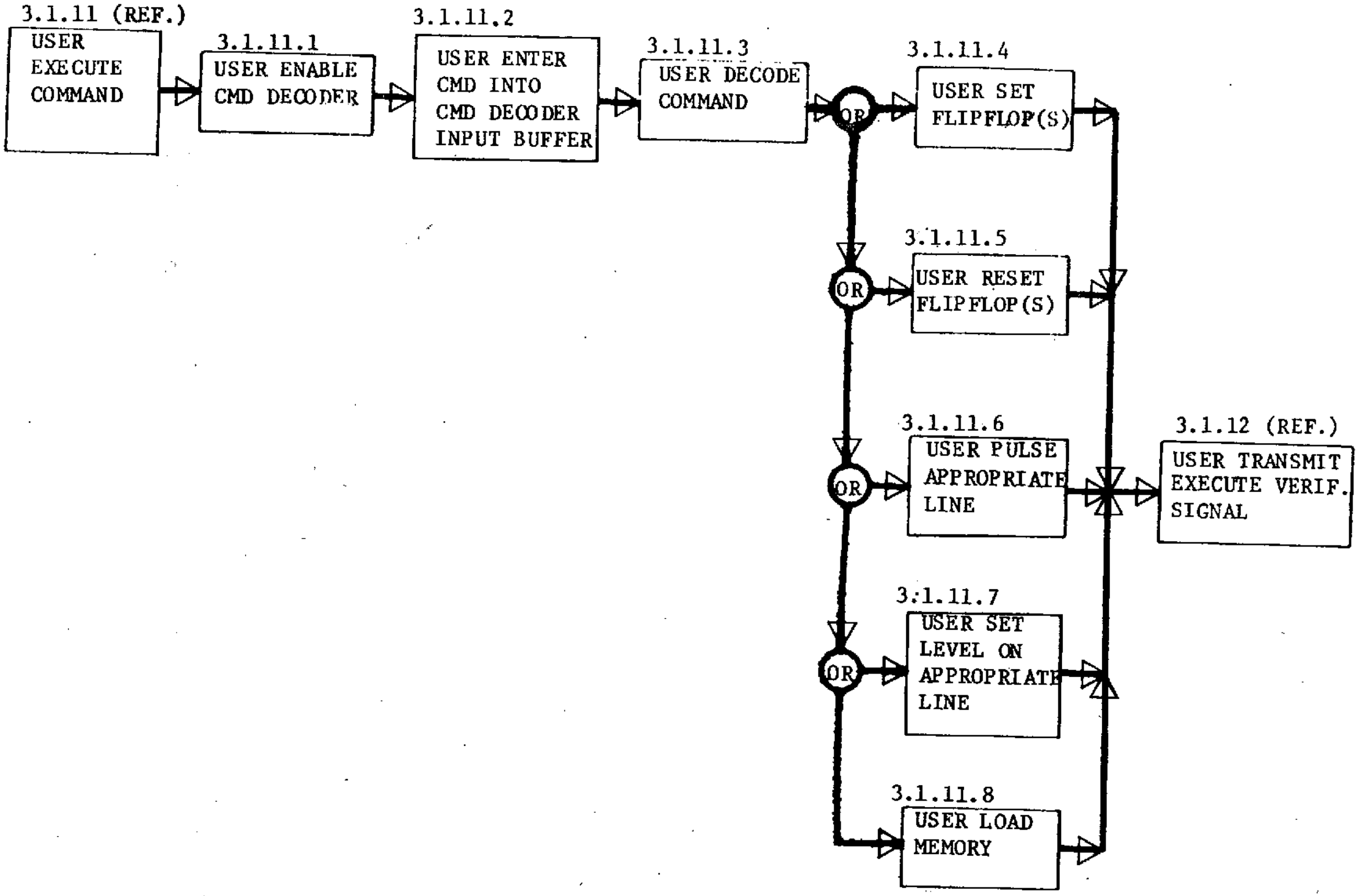


FIGURE 2-59
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.11 USER EXECUTE COMMAND

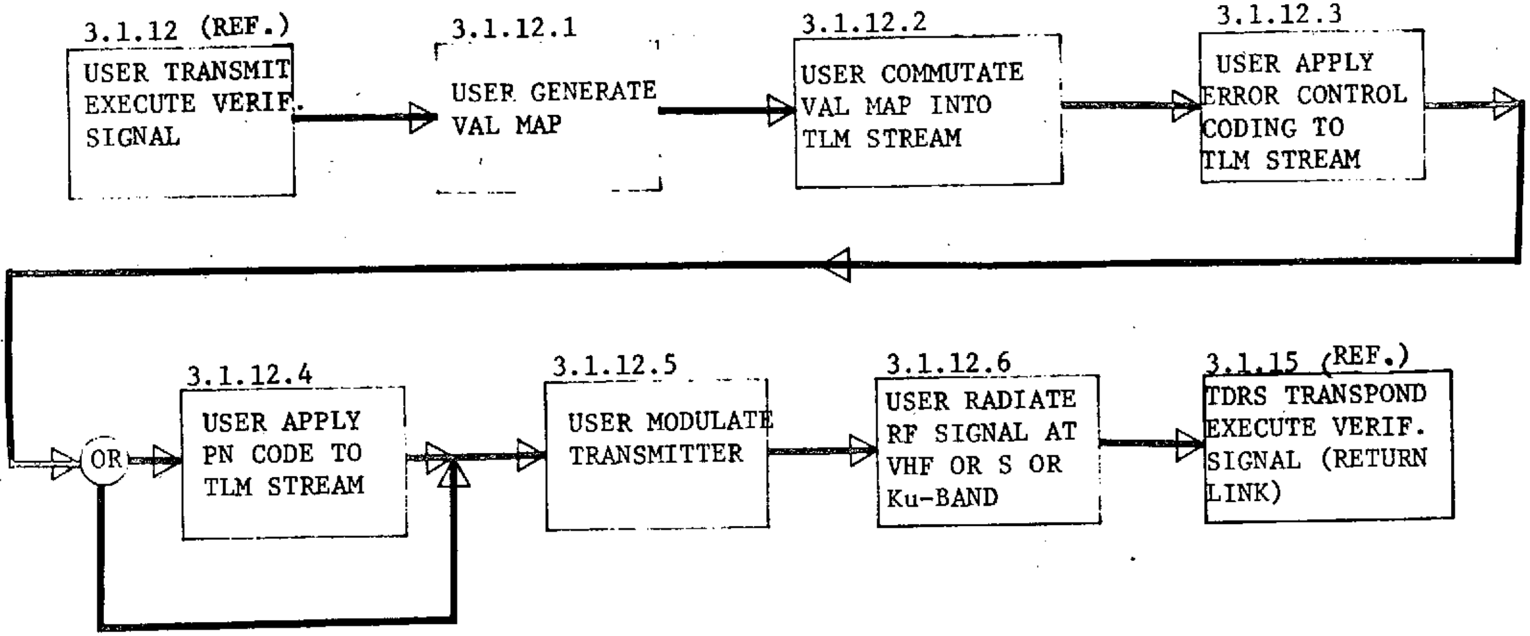


FIGURE 2-60 . THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.12 USER TRANSMIT EXECUTE VERIFICATION SIGNAL

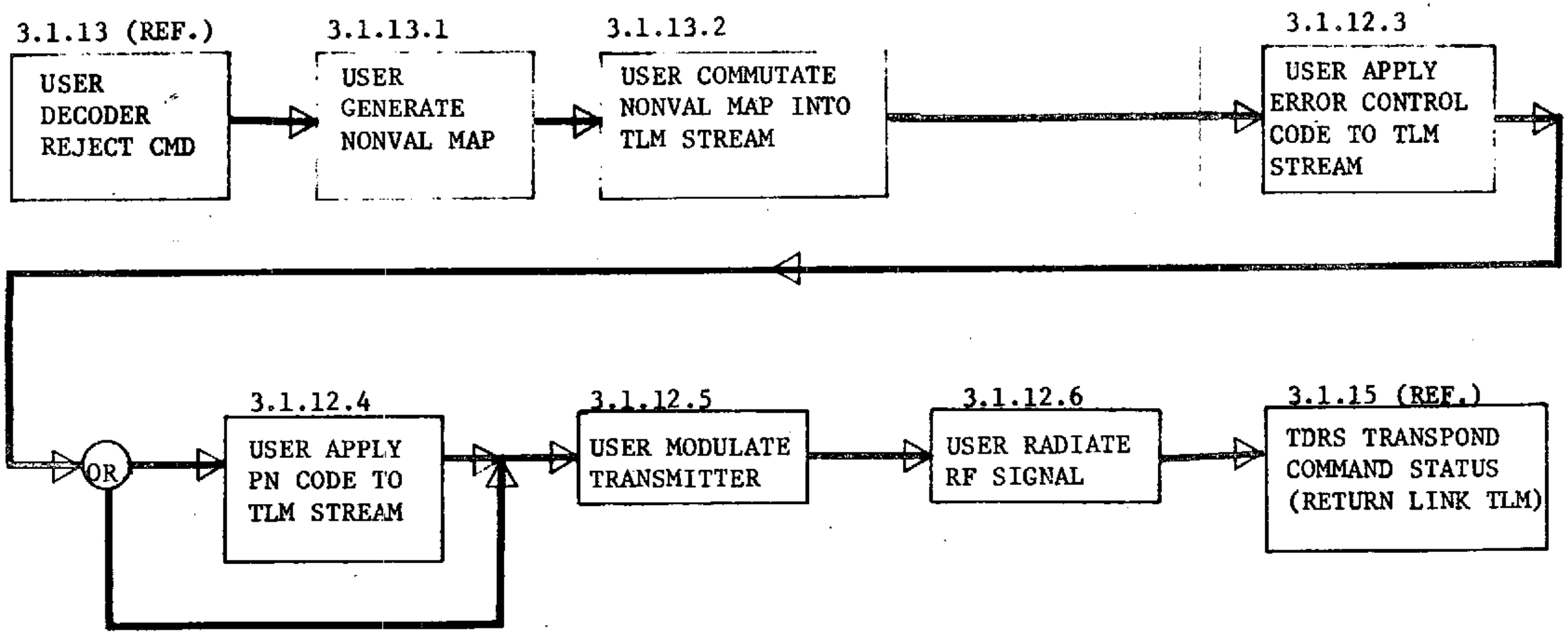


FIGURE 2-61
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.13 USER DECODER REJECT COMMAND

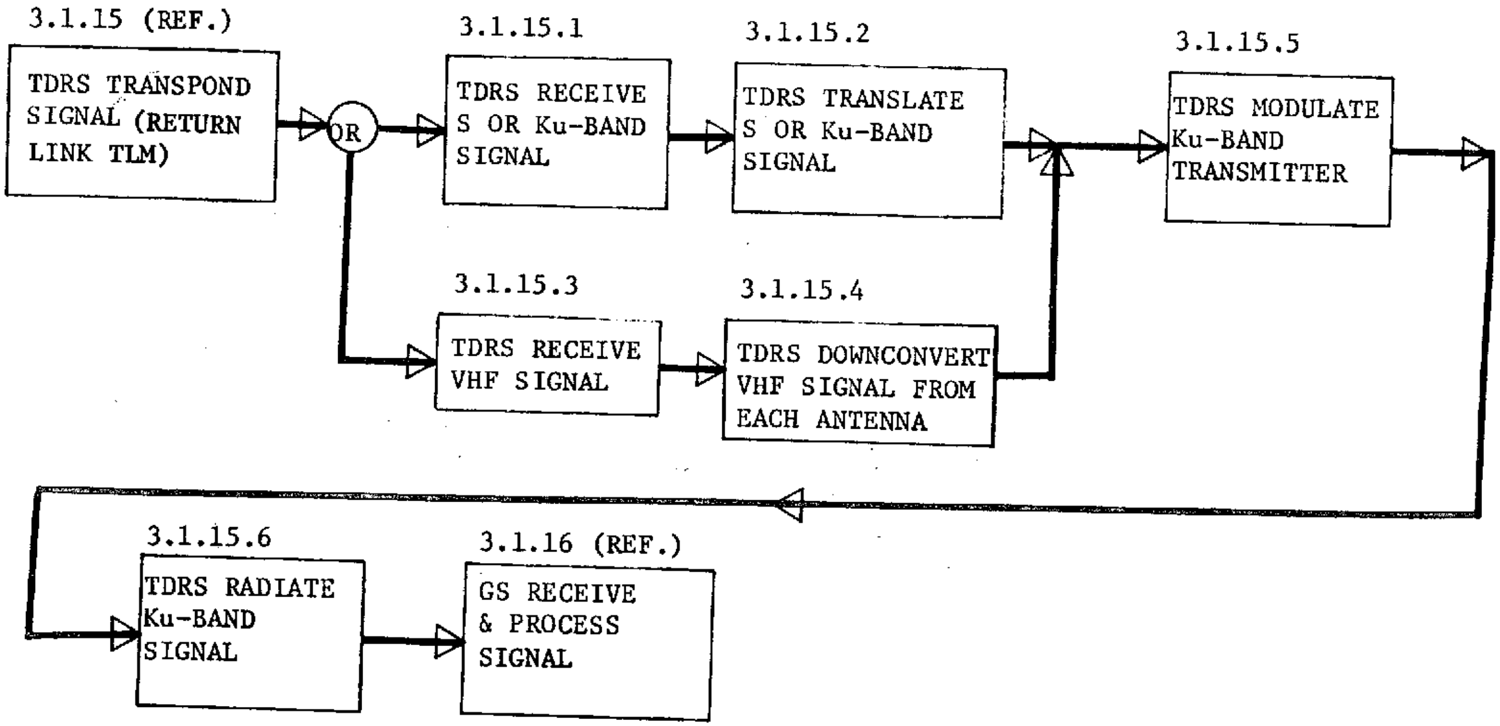


FIGURE 2-62
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.15 TDRS TRANSPOND SIGNAL (RETURN LINK TLM)

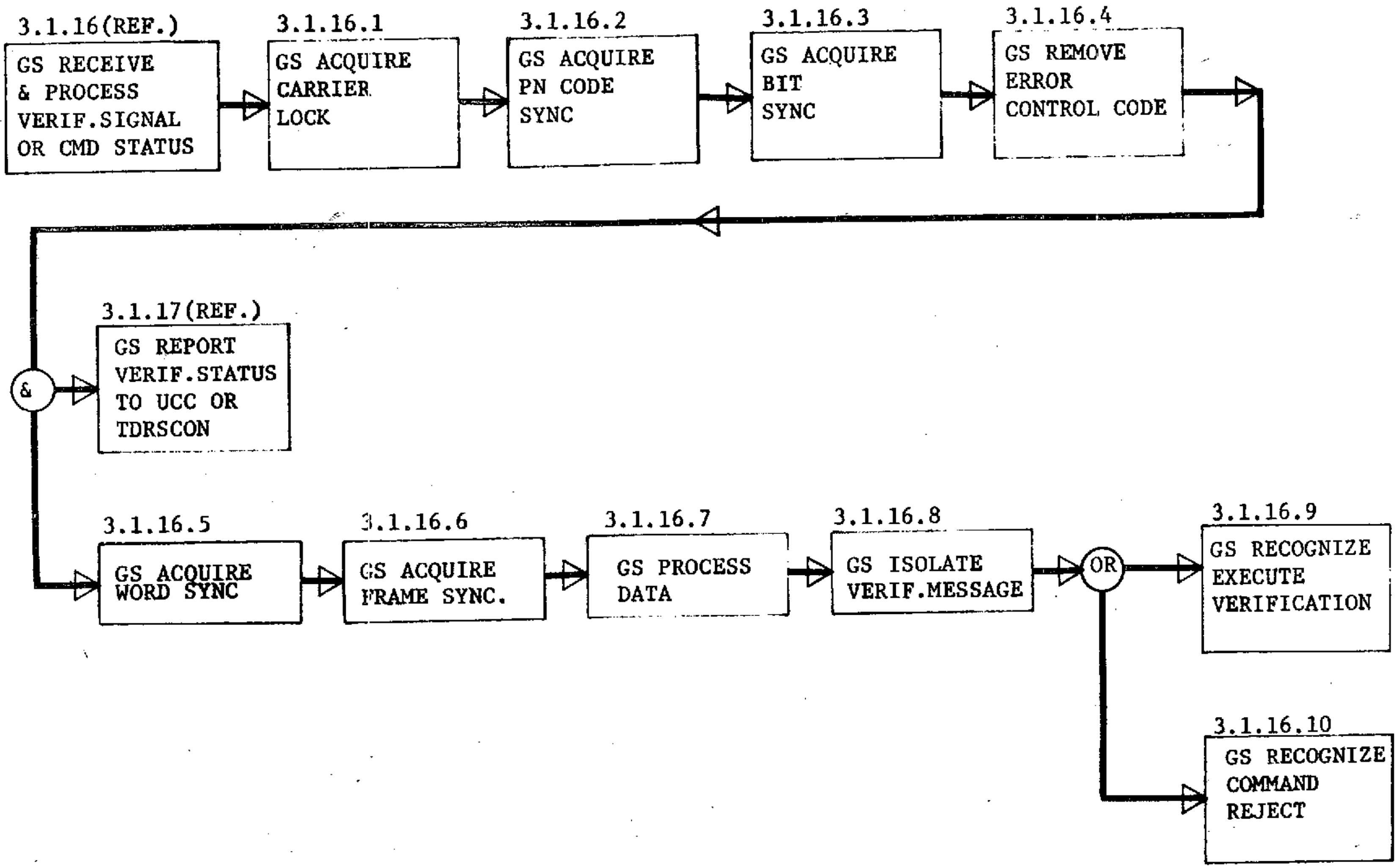


FIGURE 2-63. THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.16 GS RECEIVE & PROCESS VERIFICATION SIGNAL OR CMD STATUS

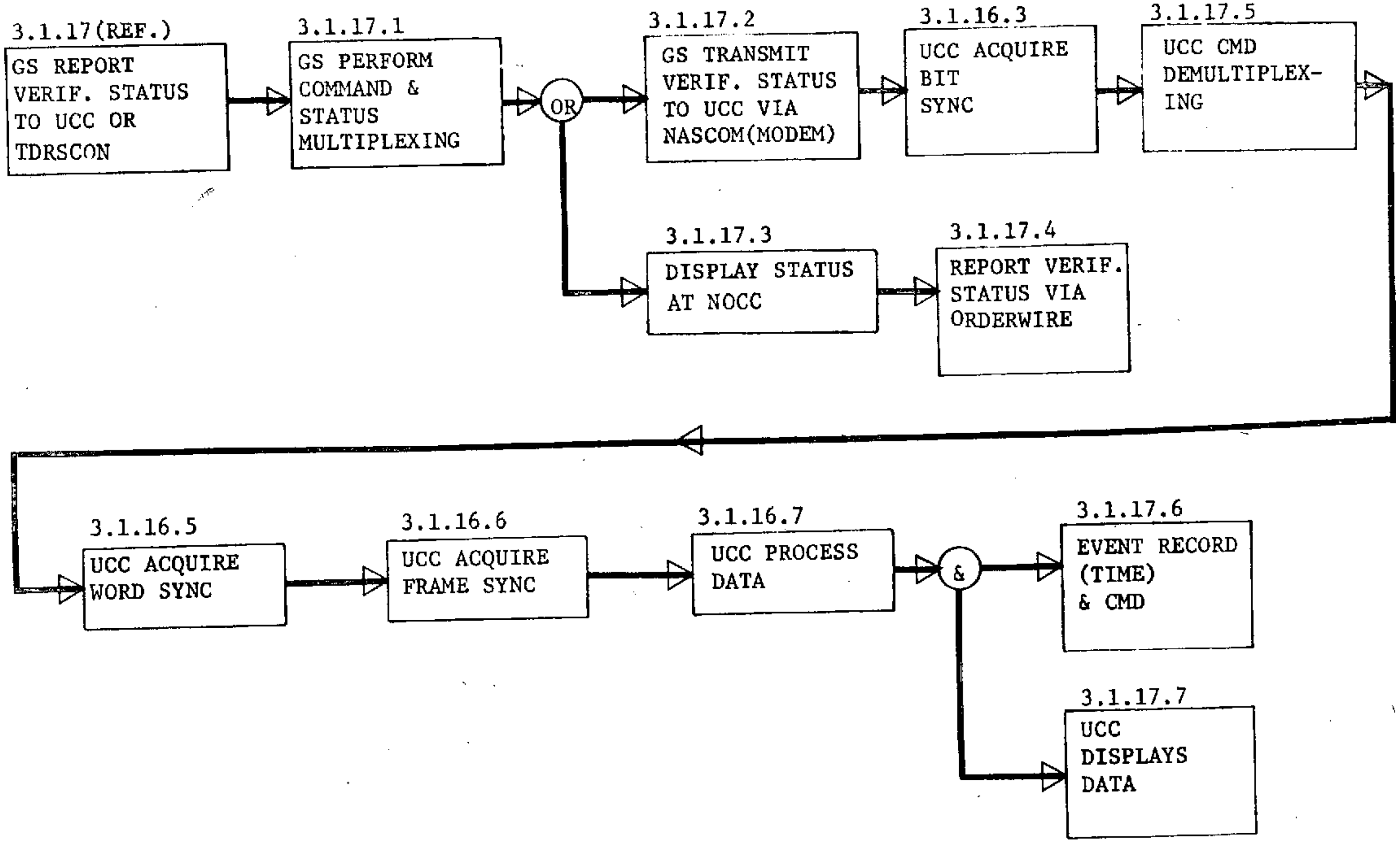


FIGURE 2-64. THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.1.17 GS REPORT VERIFICATION STATUS TO UCC OR TDRSCON

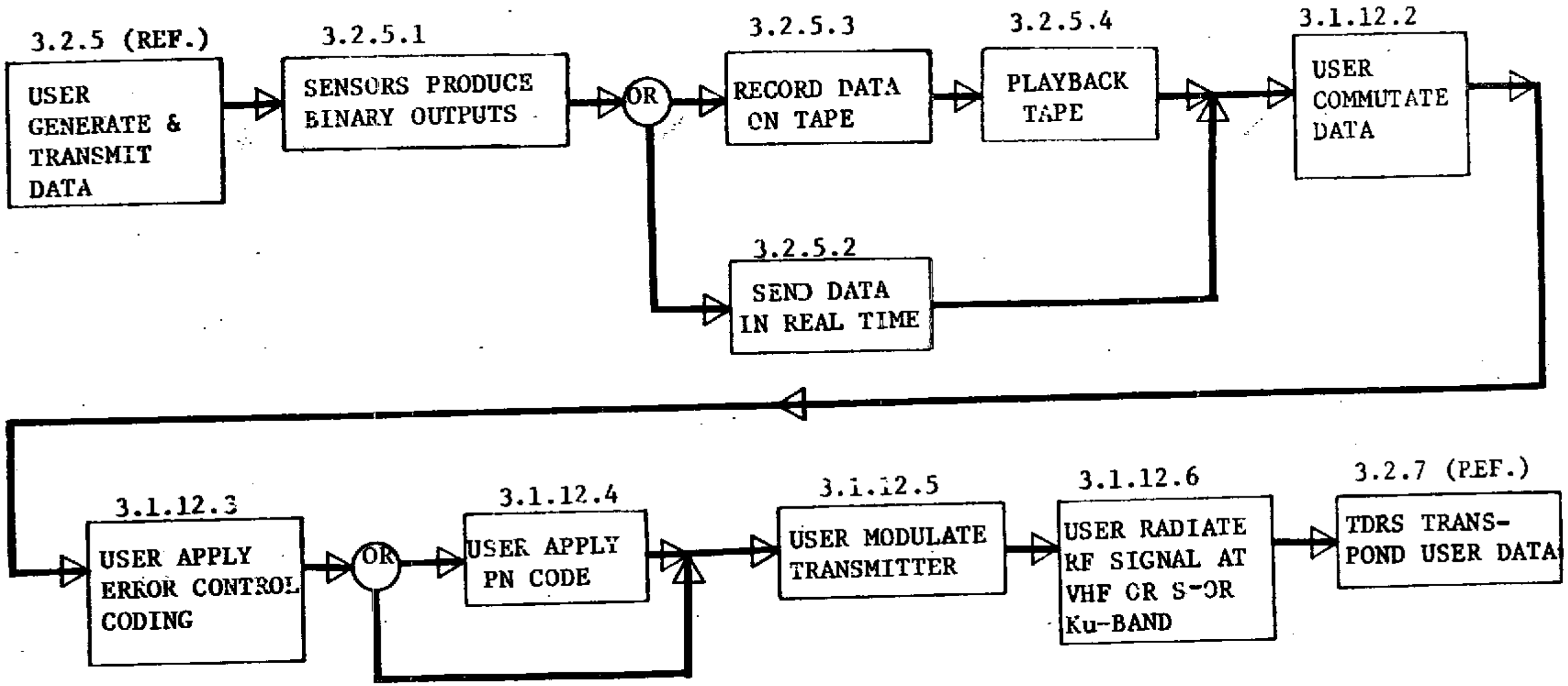


FIGURE 2-65
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.2.5 USER GENERATE AND TRANSMIT DATA

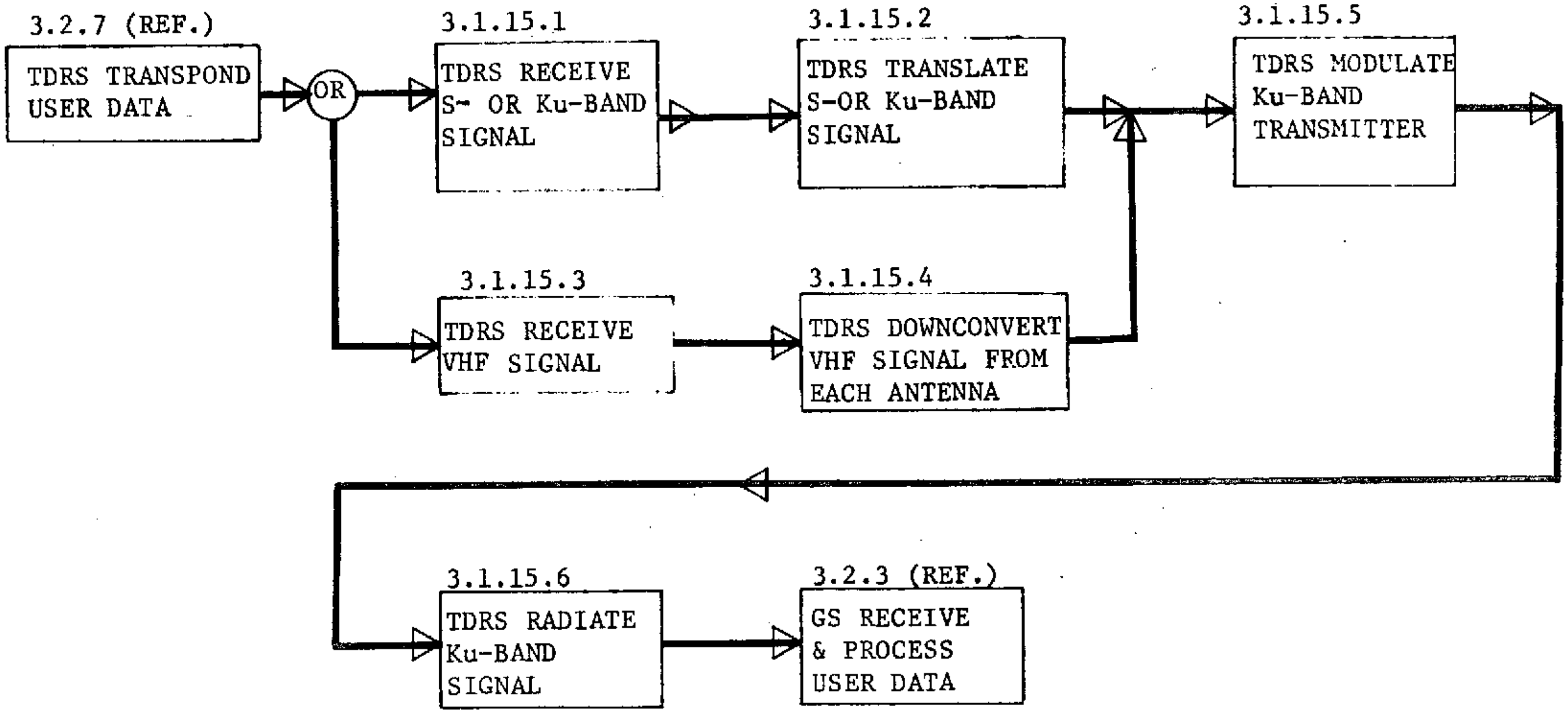


FIGURE 2-66
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.2.7 TDRS TRANSPOND USER DATA

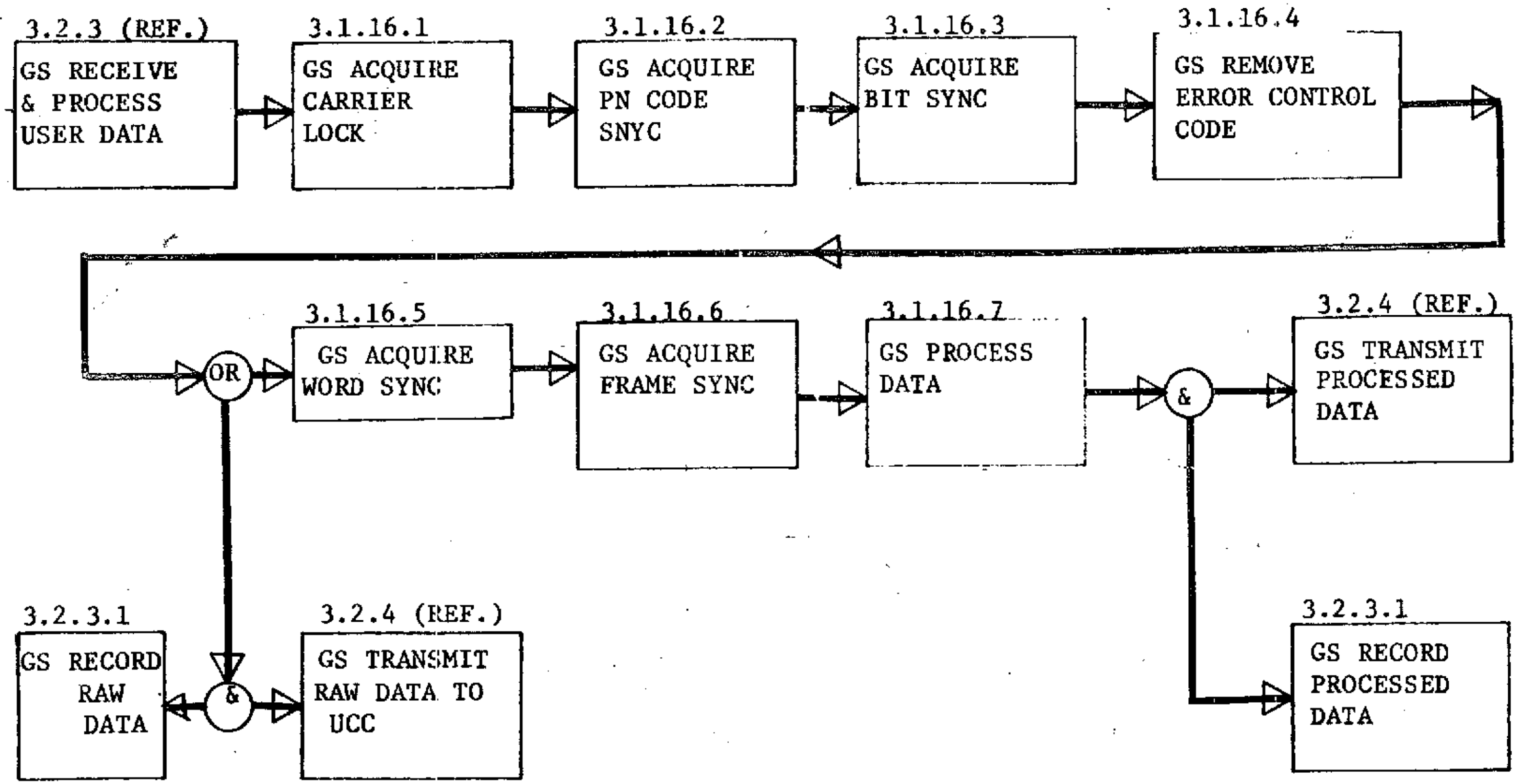


FIGURE 2-67
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.2.3 GS RECEIVE AND PROCESS USER DATA

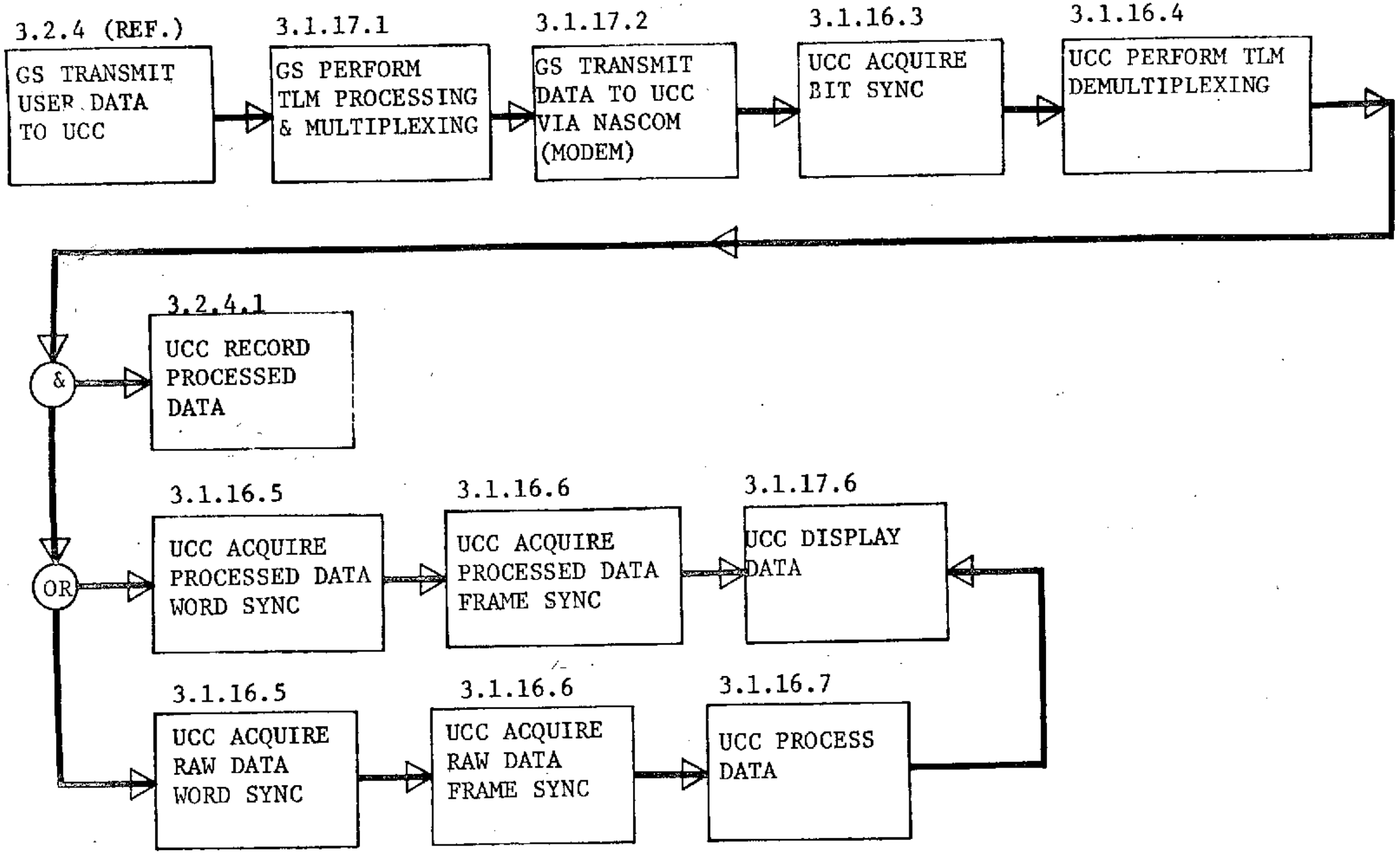


FIGURE 2-68
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.2.4 GS TRANSMIT USER DATA TO UCC

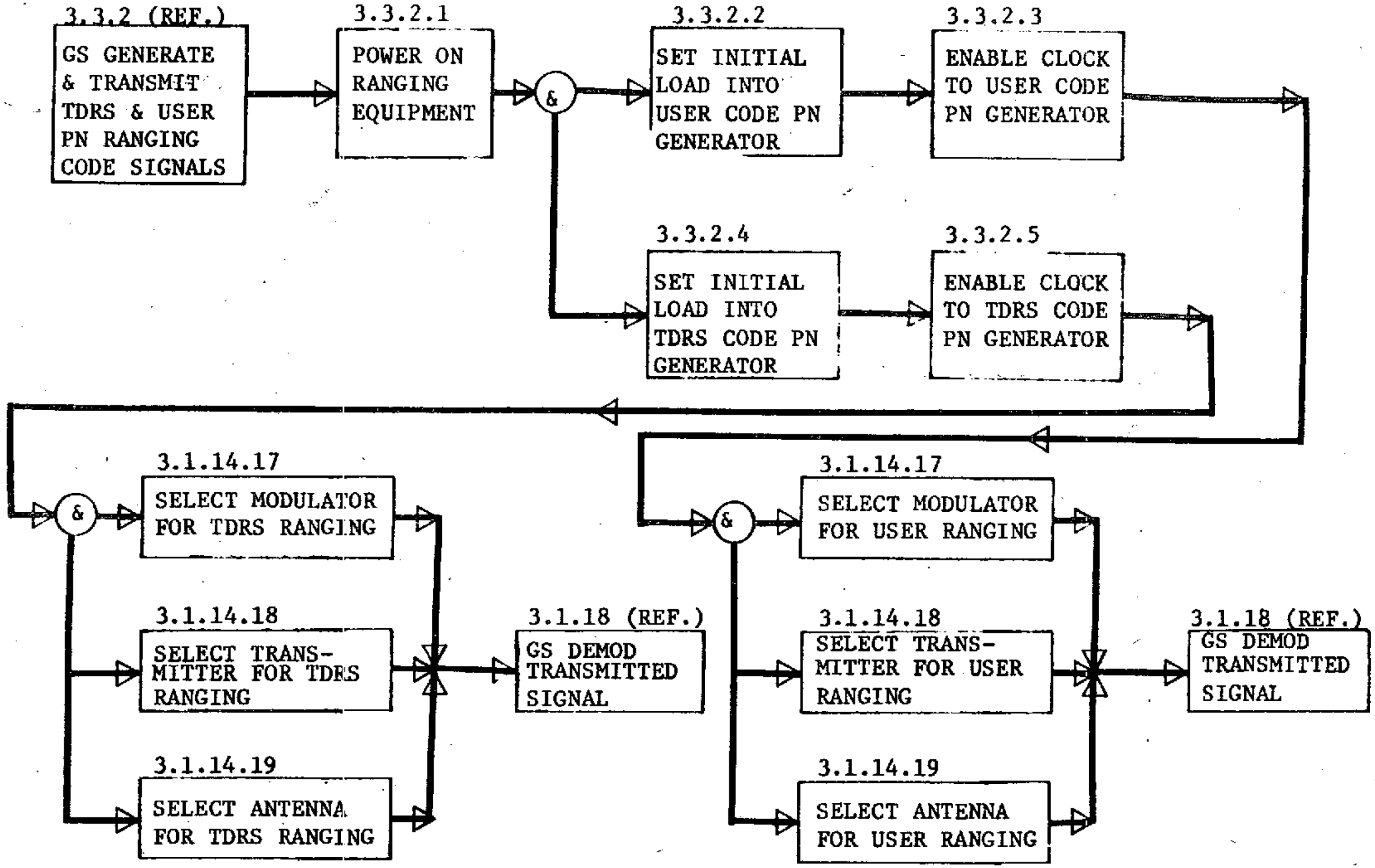


FIGURE 2-69
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.2 GS GENERATE AND TRANSMIT TDRS & USER PN RANGING CODE SIGNALS

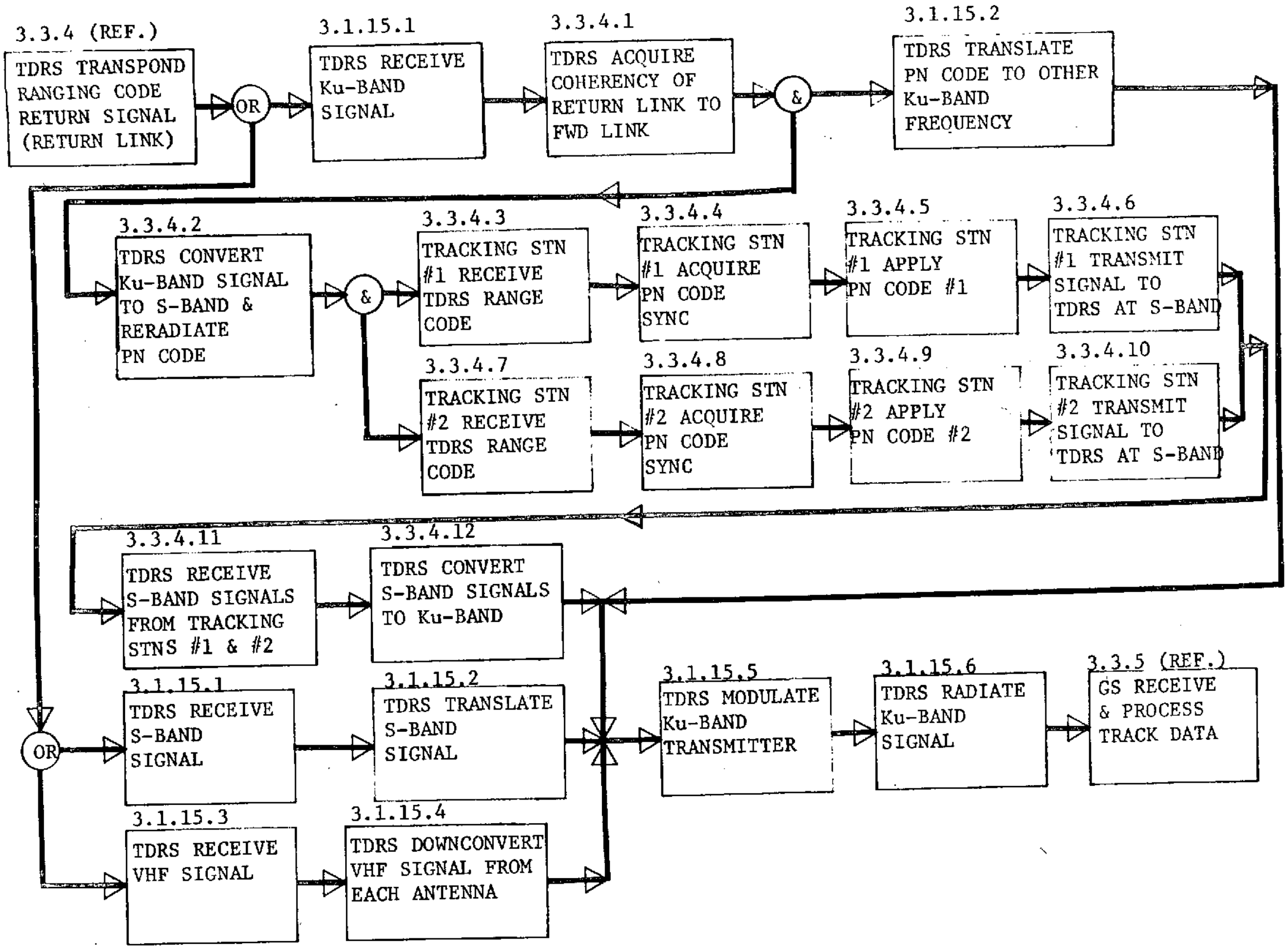


FIGURE 2-70
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.4 TDRS TRANSPOND RANGING CODE RETURN SIGNAL (RETURN LINK)

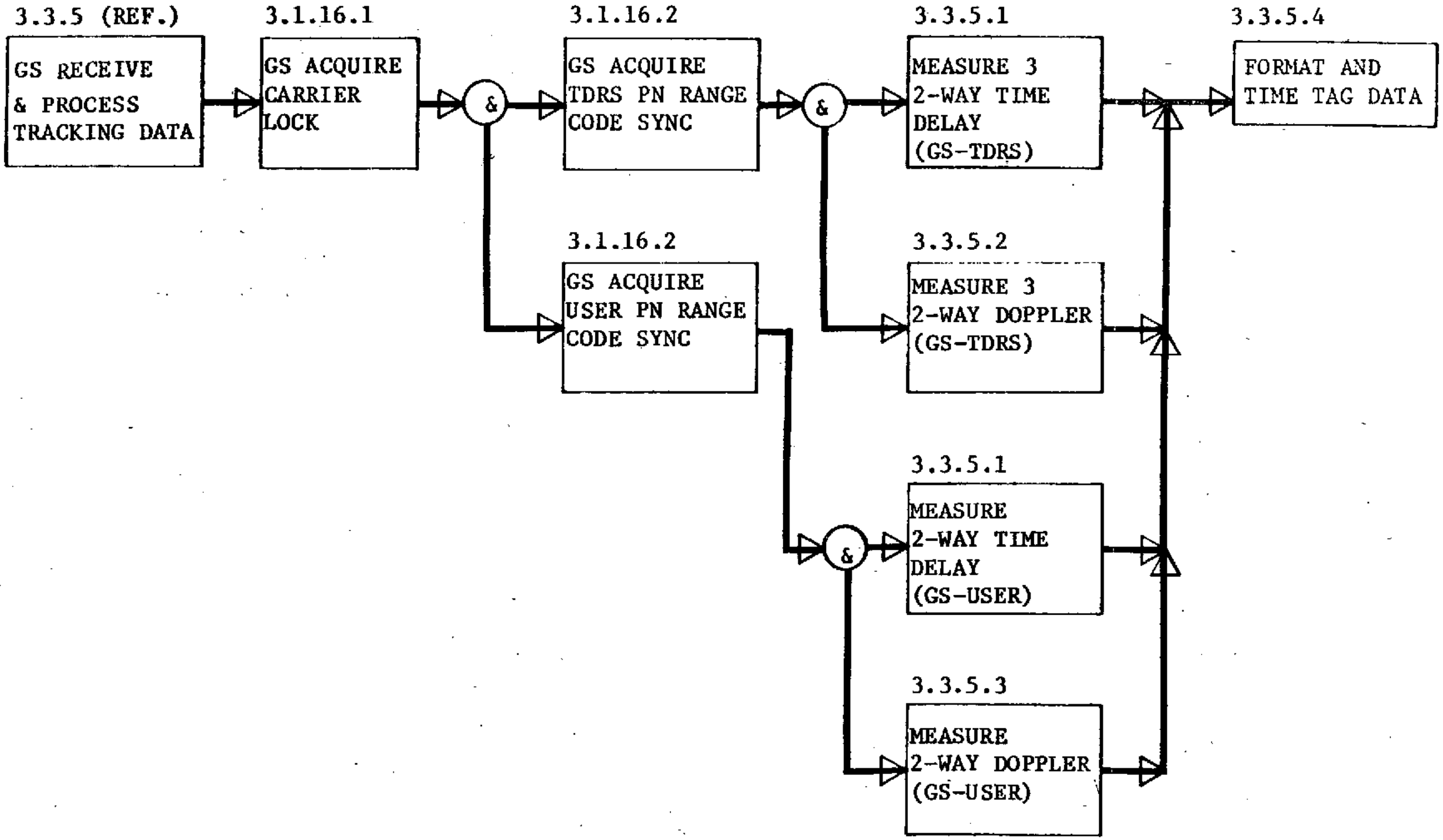


FIGURE 2-71
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.5 GS RECEIVE AND PROCESS TRACKING DATA

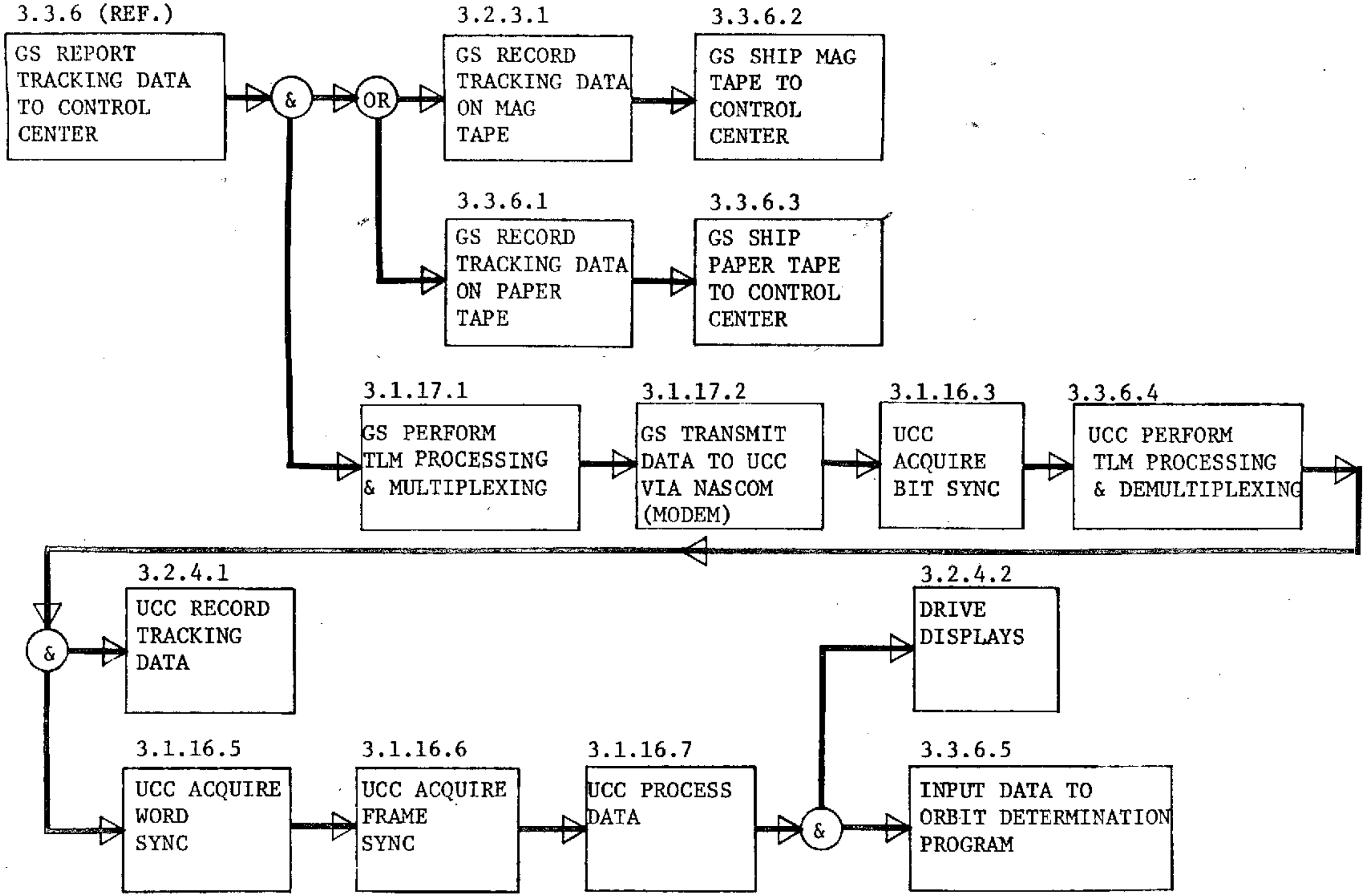


FIGURE 2-72
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.6 GS REPORT TRACKING DATA TO CONTROL CENTER

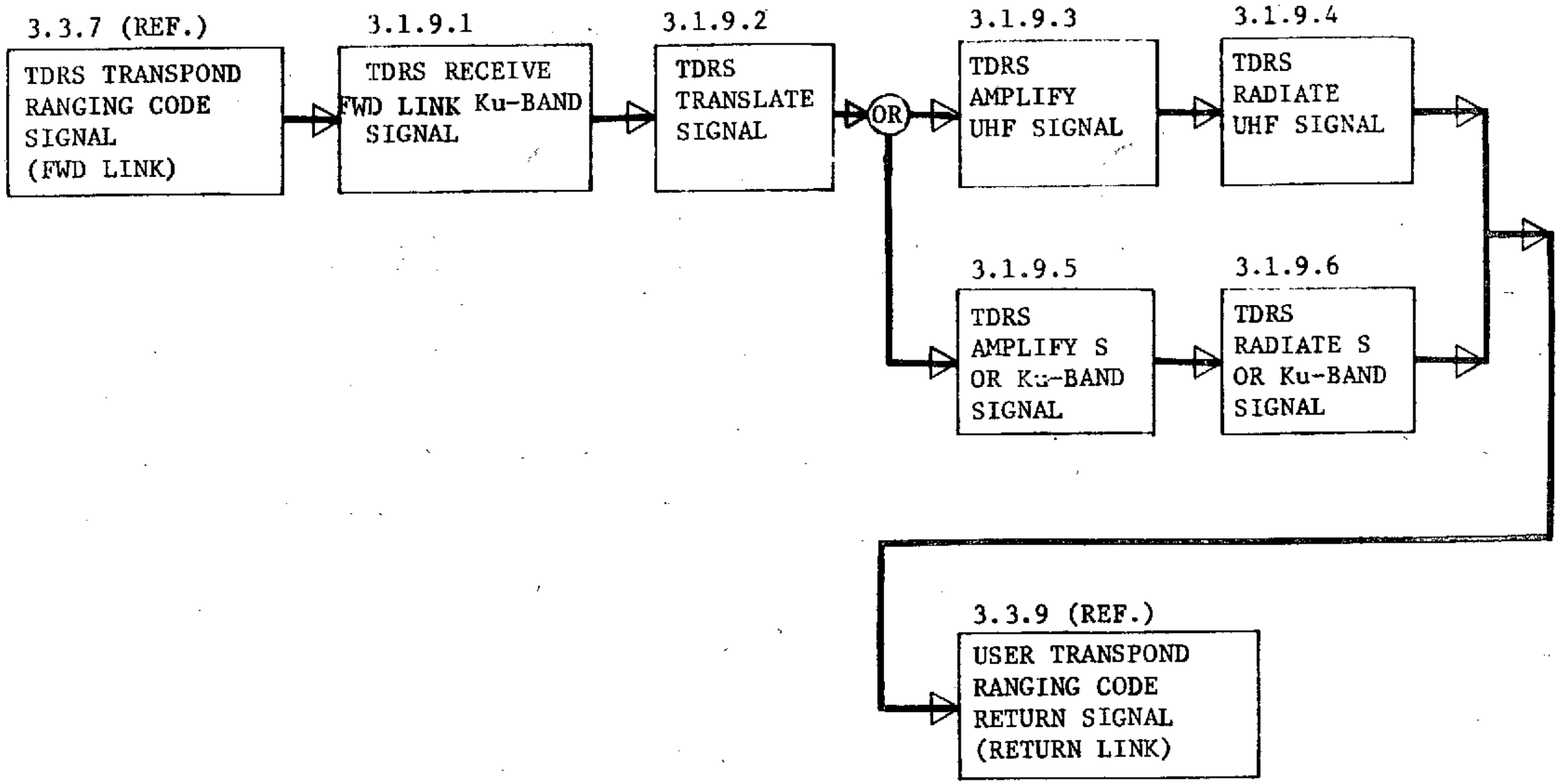


FIGURE 2-73
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.7 TDRS TRANSPOND RANGING CODE SIGNAL (FORWARD LINK)

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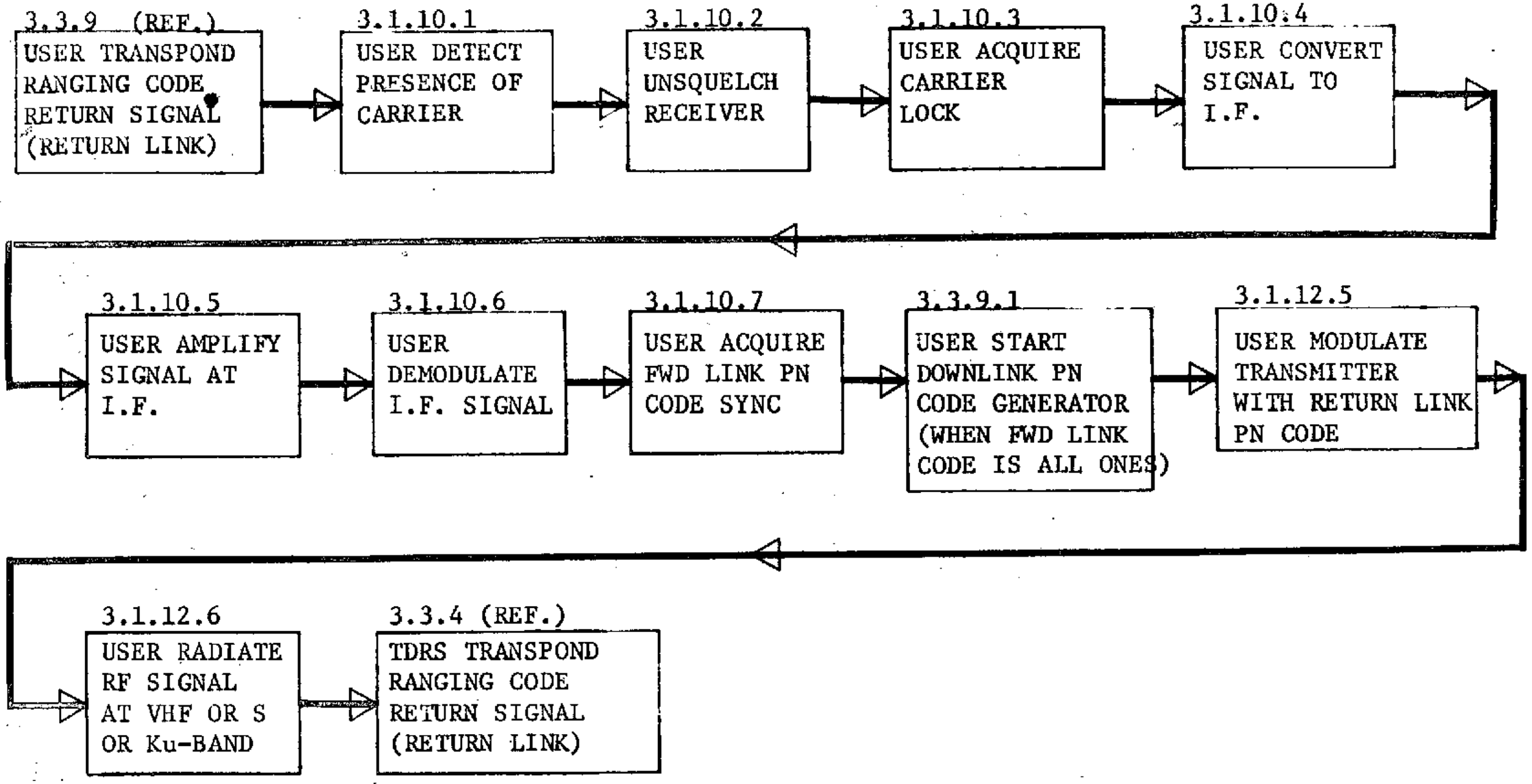

FIGURE 2-74 THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.3.9 USER TRANSPOND RANGING CODE RETURN SIGNAL (RETURN LINK)

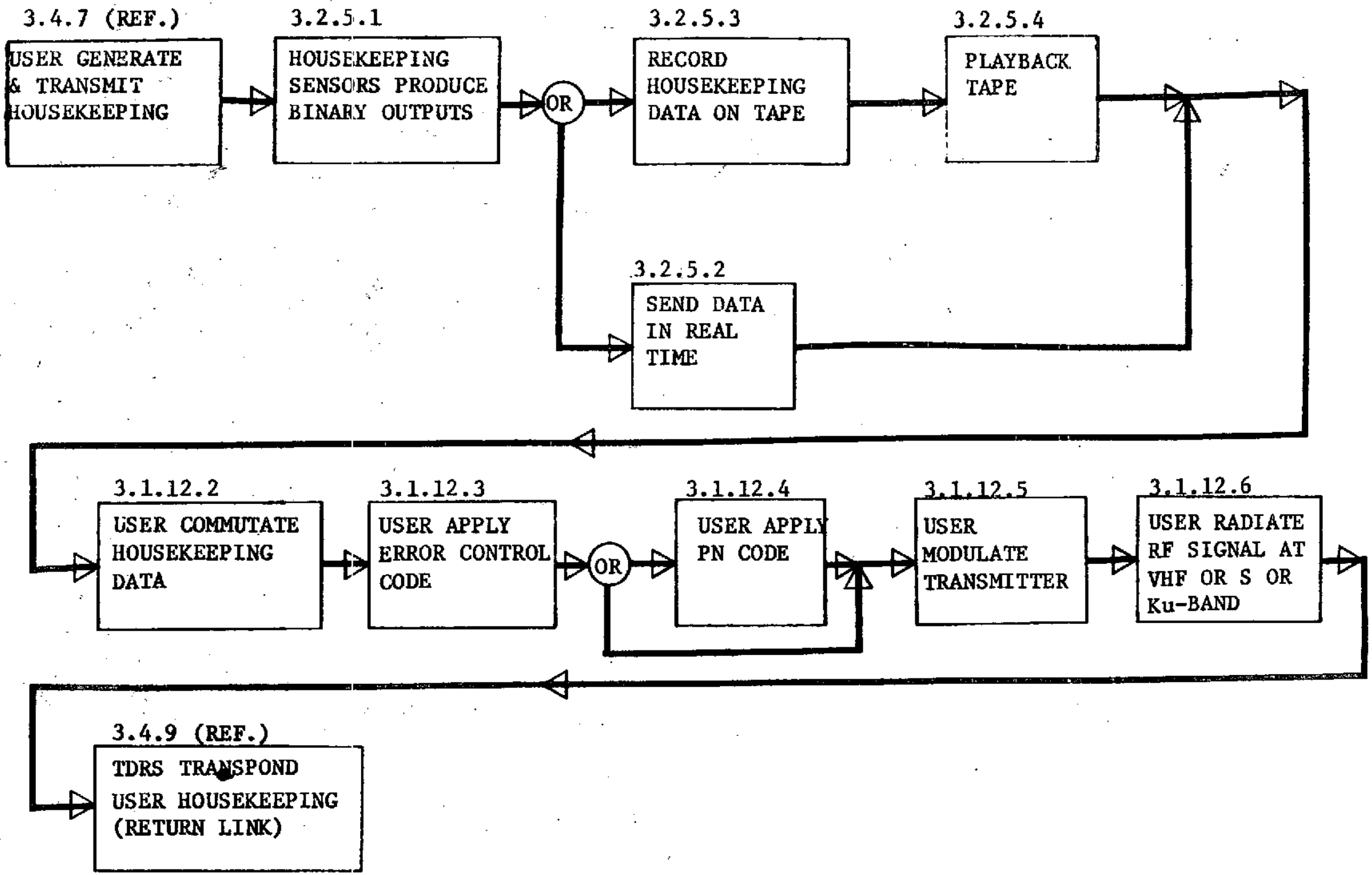

FIGURE 2-75 THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.4.7 USER GENERATE AND TRANSMIT HOUSEKEEPING

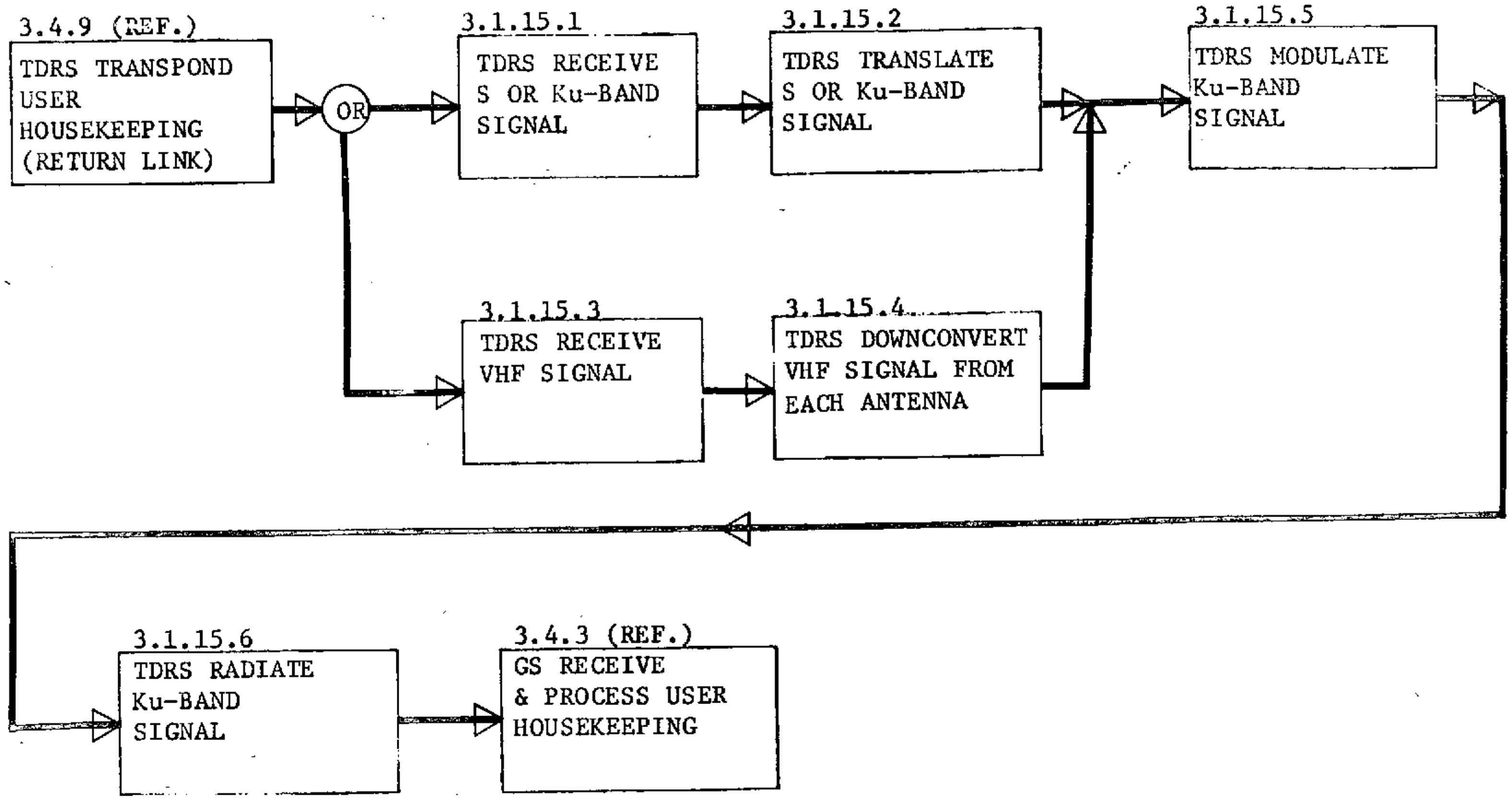

FIGURE 2-76 THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.4.9 TDRS TRANSPOND USER HOUSEKEEPING (RETURN LINK)

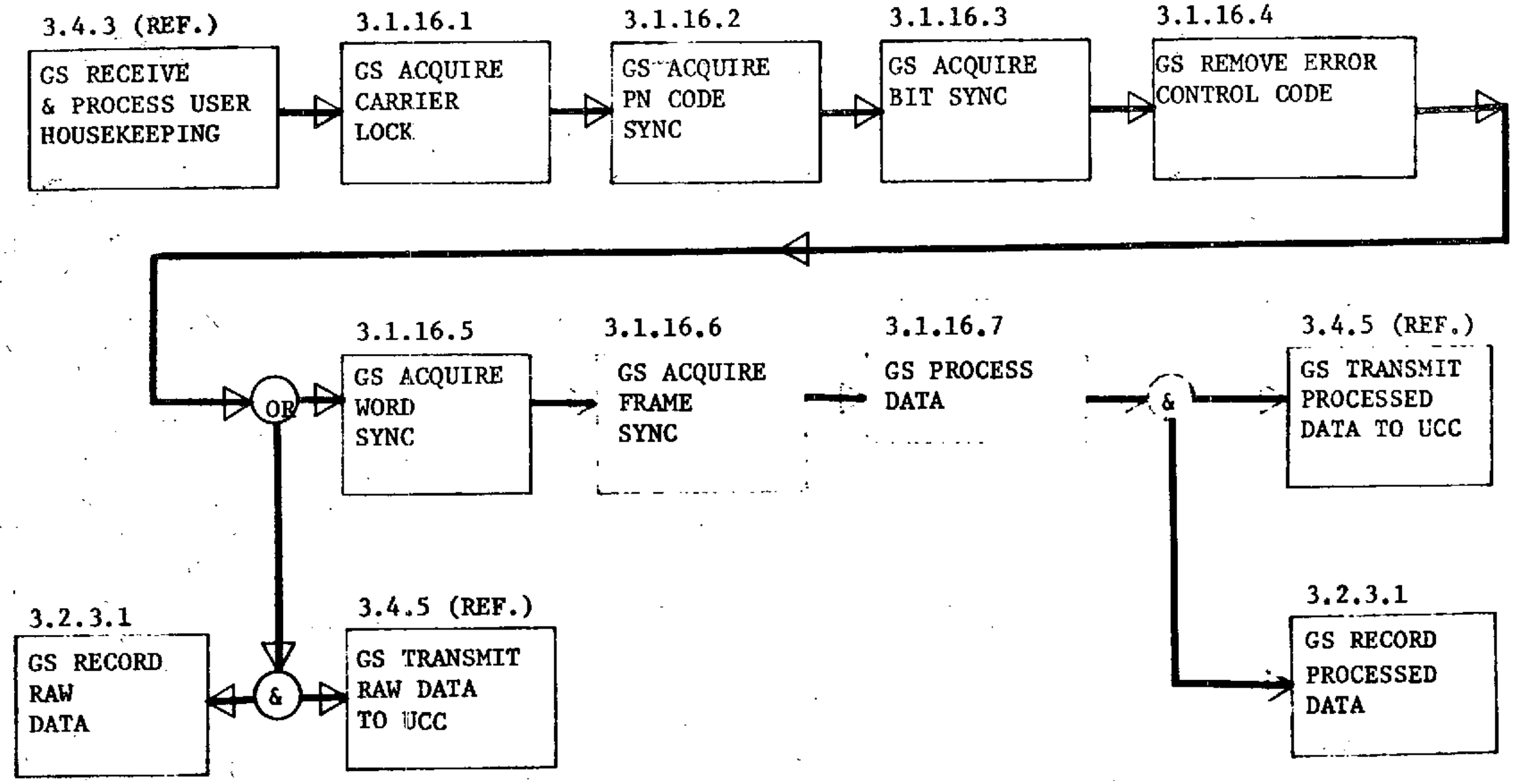

FIGURE 2-77
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.4.3 GS RECEIVE AND PROCESS USER HOUSEKEEPING

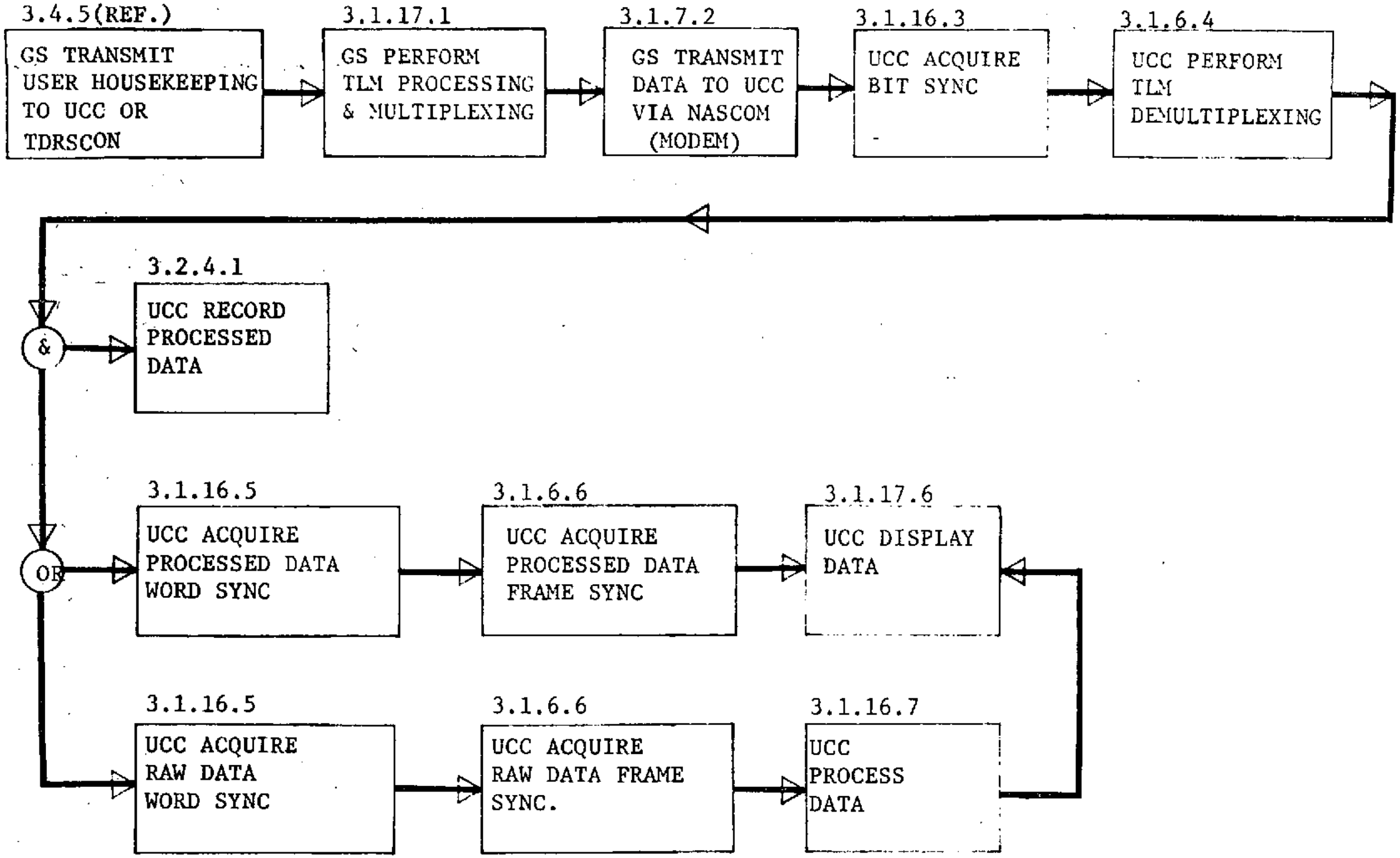

FIGURE 2-78 THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.4.5 GS TRANSMIT USER HOUSEKEEPING TO UCC OR TDRSCON

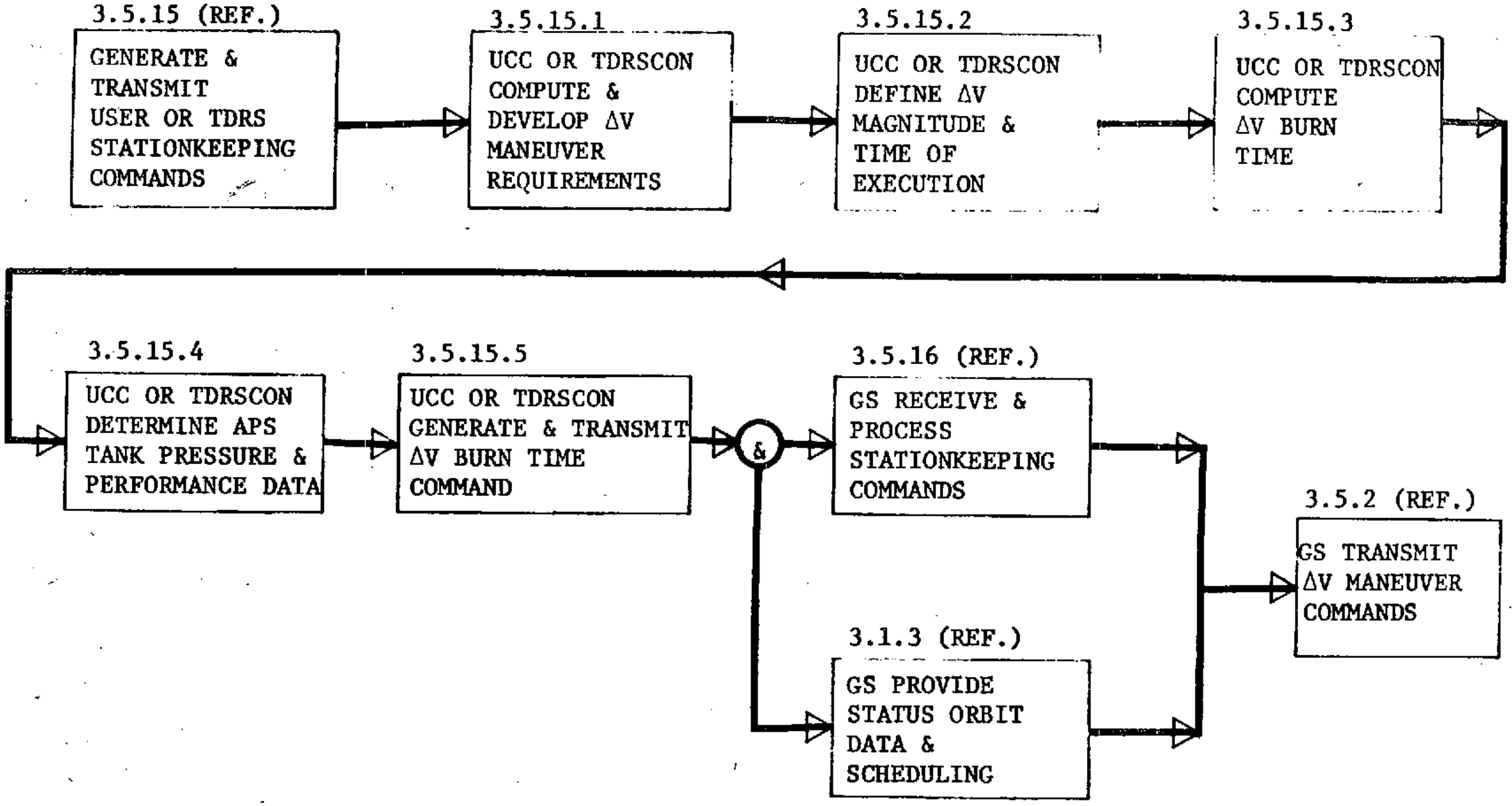

FIGURE 2-79
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.5.15 GENERATE AND TRANSMIT USER OR TDRS STATIONKEEPING COMMANDS

system tank pressure and performance data before generating and transmitting the delta V burn time command to the Ground Station for transmission to the spacecraft.

Figure 2-80 shows the TDRS receiving and processing the delta V commands. The TDRS delta V register receives the digital load and telemeters the load to the ground. It then either validates it on board (by sending back to the Ground Station a command error/rejection signal) or the Ground Station confirms the register load and transmits an execute command. In either case, the TDRS receives and processes the execute command and enables the attitude stabilization and control system delta V mode logic switch, whereupon the register begins to count down. At the appropriate countdown, the APS magnetic latching valve is energized, the appropriate thruster valves are actuated, and the thrusters are fired to complete the maneuver.

Figure 2-81 shows the thruster firing to complete the delta V maneuver. The attitude stabilization and control system delta V control mode steers the spacecraft attitude during the burn while TDRSCON monitors the status. The register enables the delta V cutoff switch, then disenables the switch, and disables the delta V mode. The coasting ASCS mode is then re-enabled before the thrusters cease firing.

The preceding functional flow diagrams provide a detailed set of operational procedures for implementing a real-time TDRS System Concept, while allowing routine procedures to be carried out wherever time is not a sensitive factor. They also exert minimum impact on existing or planned organizations and facilities, particularly in the early years of the system operation. Nevertheless, there is inherent flexibility in the system concept and in its functions and operations to permit growth and modification to allow for varying degrees of automation, centralization, and sophistication.

2.2.4 TDRS Operational Phase Sequence of Events

Figure 2-82 presents a flow diagram of a representative TDRS sequence of operational phase mission operations. It occurs after the TDRS is activated on station and is contacting users for the first time. A number of these events or operations will be simultaneous, others sequential. This flow is only representative of the many operational sequences possible with this system. Generally a user will have to be acquired, commanded, tracked, and monitored to assure it is operationally ready to participate with the TDRS in transferring data. After handover takes place to a second TDRS the data transfer is resumed. Stationkeeping occurs approximately every 17 days. The box numbers in the flow diagram refer to the applicable functional flow diagram.

Table 2-5 presents a detailed TDRS operational phase sequence of events or operations to fit the representative mission flow diagram. Each operation and the system element performing the operation are identified (User and TDRS Control Center, TDRS Network Control Center, Ground Station, User, TDRS), the applicable functional flow diagram and functional flow box referenced, and a rationale for each event or operation presented. All operations are numbered consecutively. Operations 1-97 deal with LDR user operations, 201-335 with MDR user operations and 401-446 with TDRS operations.

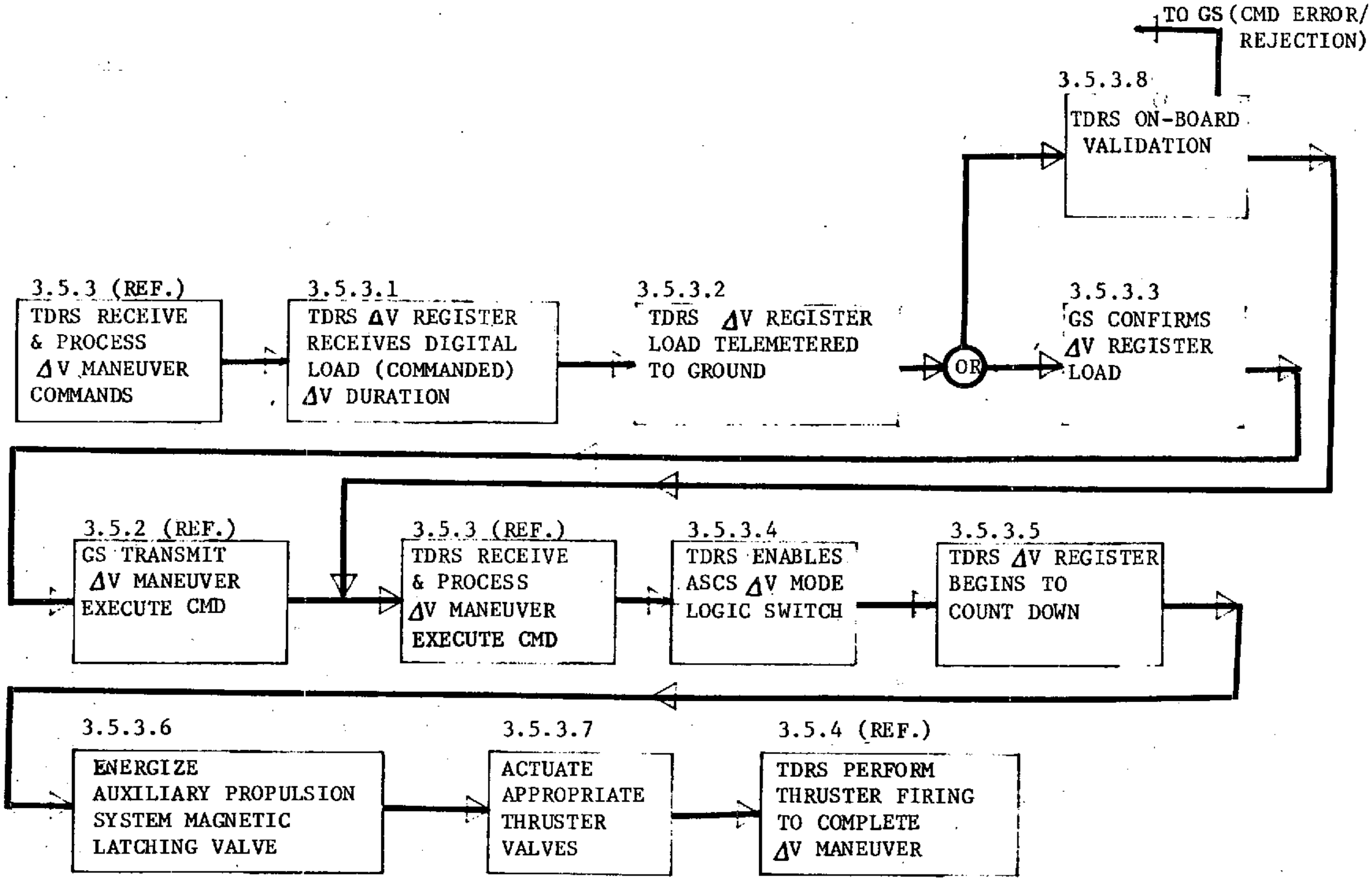

FIGURE 2-80
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.5.3 TDRS RECEIVE & PROCESS ΔV MANEUVER COMMANDS

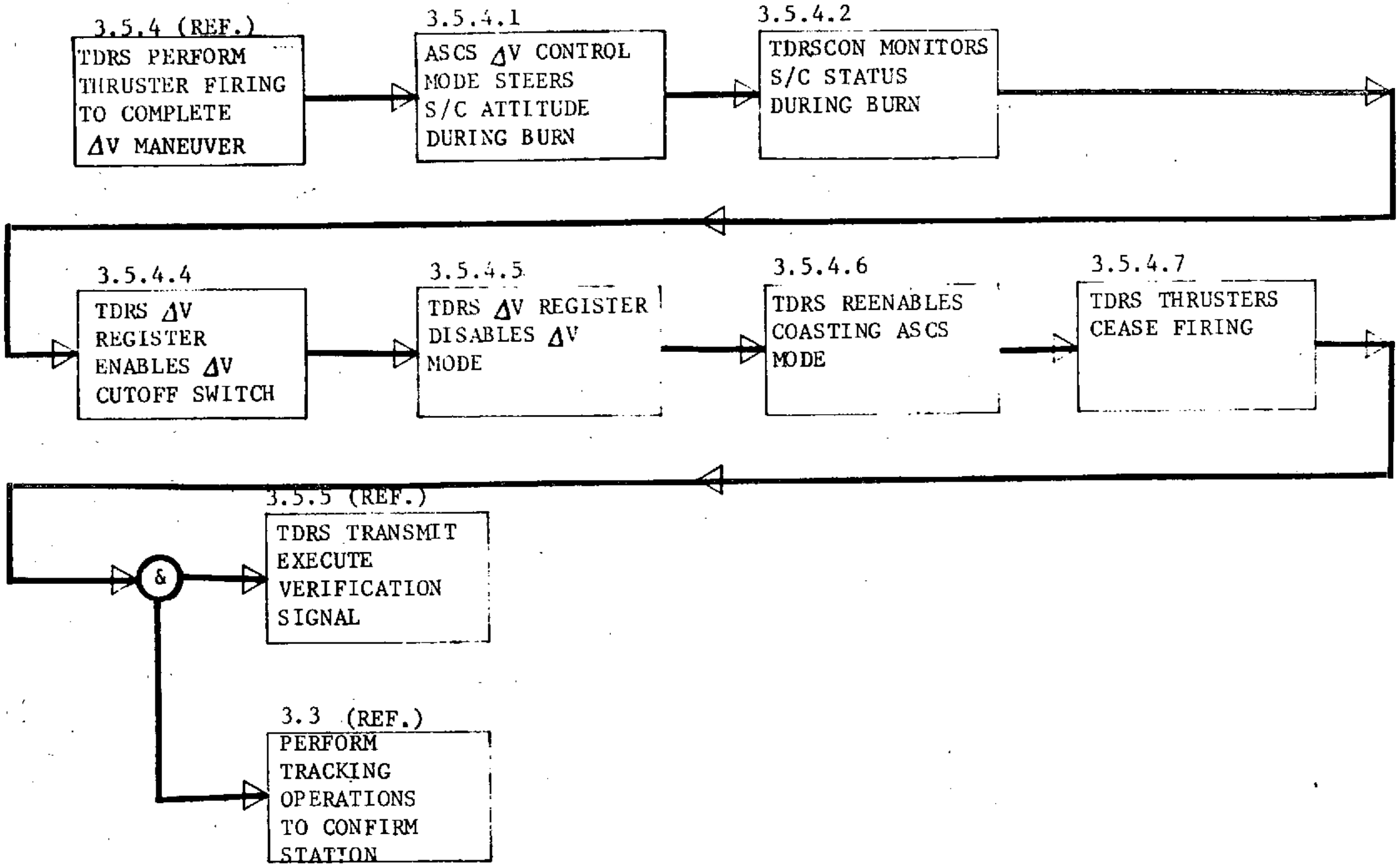

FIGURE 2-81
THIRD/FOURTH LEVEL FUNCTIONAL FLOW DIAGRAM
3.5.4 TDRS PERFORM THRUSTER FIRING TO COMPLETE ΔV MANEUVER

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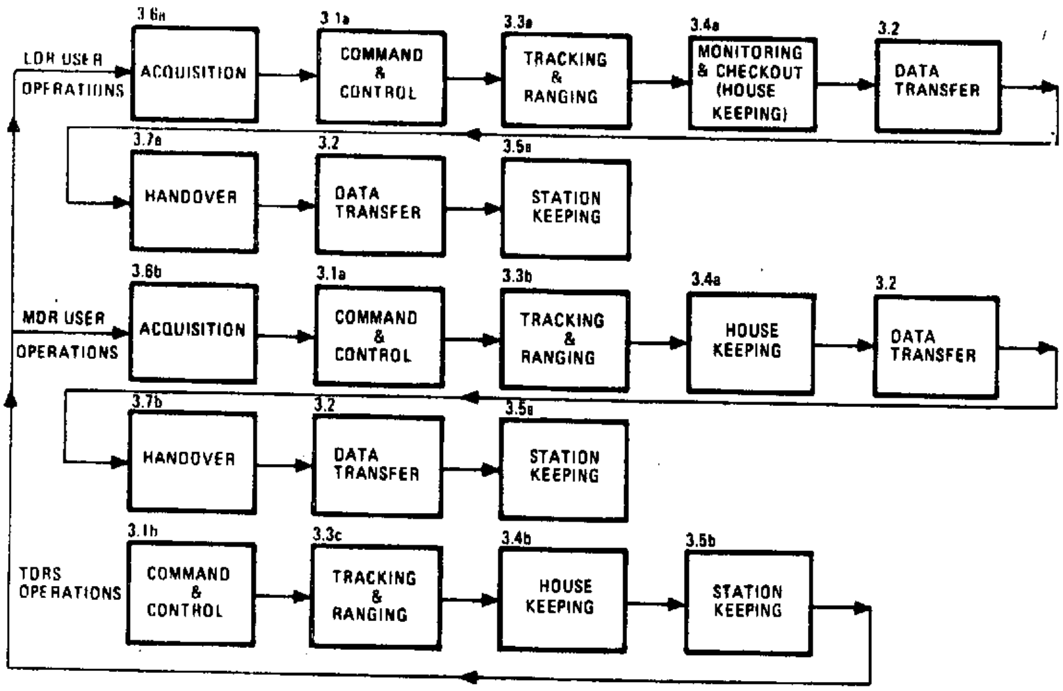

Figure 2-82. Operational Phase-Representative Mission Operations

Table 2-5A. TDRS Operational Phase Sequence of Events (LDR User Operations)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
	ACQUIRE LDR USER		(3.6a)	
1	Generate and transmit LDR User acquisition mode	UCC and NOCC	3.6.15a	User Control Center determines acquisition mode requirements and priority status, provides spacecraft orbital parameters, sends to NOCC comm processor
2	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
3	Receive and process acquisition mode	NOCC and GS	3.6.16a	NOCC comm processor receives commands, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
4	Generate and transmit carrier signal with frequency and VHF transmitter activation command	GS	3.6.1a	Ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to user via TDRS, also for cmds to activate the required frequency and the VHF transmitter, transmits via Ku-band forward link
5	Transpond carrier and commands	TDRS	3.6.2a	TDRS receives forward link Ku-band signals, translates to UHF, amplifies signal, and radiates UHF signal to user
6	Receive and process carrier and commands	User	3.6.3a	User detects carrier and cmd signals, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal; acquires PN code, bit, word, frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
7	Activate command frequency and VHF transmitter ON	User	3.1.11	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes cmd
8	Transmit return carrier and modulation	User	3.6.17a	User detects carrier, acquires carrier lock, converts signal to I.F., demodulates signal, acquires sync, starts return link carrier generator, modulates and radiates carrier with modulation on VHF return link
9	Transpond return carrier and modulation	TDRS	3.6.18a	TDRS receives the VHF carrier and modulation, downconverts VHF signal from each antenna, modulates Ku-band transmitter, and radiates carrier and modulation on Ku-band
10	Receive and process carrier and modulation	GS	3.6.19a	Ground station receives carrier and modulation, acquires carrier lock, acquires PN code, bit word and frame sync, removes error control code, and can now establish normal LDR user operations
	COMMAND & CONTROL - LDR USER		(3.1a)	
11	Generate and transmit LDR user command	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
12	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
13	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives commands, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
14	Transmit command signal	GS	3.1.14	TDRS ground station receives real-time command, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal

Table 2-5A. TDRS Operational Phase Sequence of Events (LRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
15	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, frame sync, removes error control code and compares transmitted with recovered signals as a check on ground systems
16	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time decay in transmitter, bit-wise Mod-2 sum stored and recovered signals; if sum indicates no error terminate transmission; if sum indicates error, generate and/or transmit a new command
17	Terminate transmission of correct command	GS	3.1.20	If sum indicates no error, as above, computer ceases outputting cmd, modulator and PA are placed in standby; time of cmd cessation is logged and equipment status info is updated
18	Transpond command signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal, and radiates UHF signal to user
19	Receive and process command	User	3.1.10	User detects carrier, unsquelches recv'r, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters command into buffer storage, strips off error correcting or detecting code, checks for validity before execution
20	Execute command	User	3.1.11	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes cmd
21	Transmit execute verification signal	User	3.1.12	User generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal at VHF
22	Transpond execute verification signal	TDRS	3.1.15	TDRS receives VHF signal, downconverts signal from each antenna, modulates Ku-band transmitter, and radiates Ku-band signal
23	Receive and process execute verif. signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verif. status to UCC and acquires word and frame sync, processes data and isolates verif. message and recognizes execute verification
24	Report execute verification to UCC	GS and UCC	3.1.17	Ground station performs verif. cmd multiplexing, transmits verif cmd through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays cmd data
25	User decoder reject cmd	User	3.1.13	Instead of execute (3.1.11), user generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates transmitter and radiates RF signal on VHF
26	Transpond command reject	TDRS	3.1.15	TDRS receives VHF signal, downconverts signal from each antenna, modulates Ku-band transmitter, and radiates Ku-band signal
27	Receive and process command reject	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports cmd reject to UCC and acquires word and frame sync, processes data and isolates
28	Forward command reject signal to UCC	GS	3.1.17	Ground station performs multiplexing, transmits cmd reject signal through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays status data

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
	TRACK & RANGE - LDR USER		(3.3a)	
29	Generate and transmit user tracking mode	UCC and NOCC	3.3.13	User Control Center determines tracking requirements and priority status, provides spacecraft orbital parameters, sends to NOCC comm processor
30	Receive and process tracking mode	NOCC and GS	3.3.14	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
31	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program inputs
32	Generate and transmit user PN ranging code signal to TDRS and user	GS	3.3.2	Power is put on ranging equipment, initial load is set into TDRS and user PN code generators and clock is enabled to TDRS and user PN code generators, and the modulator, transmitter and antenna selected for TDRS and user ranging and radiates ranging signal to TDRS and user on Ku-band (or on the S-band tracking link, or on VHF if on backup TT&C link)
33	Transpond user ranging code signal to user (forward link)	TDRS	3.3.7	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal, and radiates UHF signal to user
34	Transpond user ranging code return signal to TDRS (return link)	User	3.3.9	User detects presence of carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code sync, starts return link PN code generator, modulates transmitter with PN code, and radiates RF signal at VHF
35	Transpond user ranging code return signal to ground (return link)	TDRS	3.3.4	TDRS receives VHF signal from user, downconverts, modulates Ku-band transmitter and radiates Ku-band signal to ground
36	Transpond TDRS ranging code return signal (return link)	TDRS	3.3.4 3.3.21 3.3.22 3.3.23	TDRS receives Ku-band signal, acquires coherency of return-to-forward links, translates PN code to other Ku-band frequency and modulates Ku-band transmitter and radiates Ku-band signal to the ground station; may also convert Ku-band signal to S-band and reradiate PN code, then perform tri-lateration operation; Tracking Stations #1 and #2 receive the TDRS S-band range code, acquire PN code sync, apply PN code 1 and 2, transmit signals to TDRS at S-band, TDRS receives S-band signals from Tracking Stations 1 and 2, converts to Ku-band, modulates the Ku-band transmitter and radiates Ku-band signal to the ground station; or TDRS may receive S-band ranging signals by initial tri-lateration operation of the tracking stations, with return S-band transponded directly to the Tracking Stations 1 and 2 and reported to the ground station via NASCOM; TDRS may also receive VHF ranging signal on the backup TT&C link, downconvert from each antenna, modulate the Ku-band transmitter, and radiate Ku-band signal to the ground station
37	Receive and process TDRS and user tracking data	GS	3.3.5	Ground station acquires carrier lock, acquires TDRS and user PN range code sync, measures two-way time delay and doppler for GS-TDRS and GS-user links, and formats and time tags the data
38	Report tracking data to user and TDRS control centers	GS	3.3.6	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to control centers via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, record the data and acquire word and frame sync and process the data for displays and input to orbit determination program

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
	MONITOR & CONTROL - LDR USER (HOUSEKEEPING)		(3.4a)	
39	Generate and transmit user cmd for housekeeping	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
40	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
41	Receive and process cmd	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
42	Transmit housekeeping cmd	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operations, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal
43	Transpond housekeeping cmd (forward link)	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal and radiates UHF signal to user
44	Receive and process housekeeping command	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
45	Generate and transmit housekeeping	User	3.4.7	User housekeeping sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signal at VHF
46	Transpond user housekeeping	TDRS	3.4.9	TDRS receives VHF signal, downconverts VHF signal from each antenna, modulates Ku-band signal, and radiates Ku-band signal
47	Receive and process user housekeeping	GS	3.4.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
48	Transmit user housekeeping to UCC	GS and UCC	3.4.5	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync, and processes the data for displays and input to orbit determination program
49	Compare housekeeping to reference and evaluate	UCC	3.4.4	UCC compares input housekeeping data to stored reference data, evaluates for correctness of performance and sends new command request if required to correct
	TRANSFER DATA - LDR USER		(3.2)	
50	Generate and transmit cmd for user data	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
51	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files and develops scheduling program as inputs
52	Receive and process cmd	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
53	Transmit data command and signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits command signal

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
54	Transpond data command signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal, and radiates UHF signal to user
55	Receive and process data command signal	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
56	Generate and transmit user data	User	3.2.5	User sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signal at VHF
57	Transpond user data	TDRS	3.2.7	TDRS receives user data on VHF, downconverts VHF from each antenna, modulates Ku-band signals and radiates Ku-band signals
58	Receive and process user data	GS	3.2.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
59	Transmit user data to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data, and acquires word and frame sync, and processes the data for displays and input to orbit determination program
	HANDOVER-LDR USER		(3.7a)	
60	Generate and transmit LDR user handover mode	UCC and NOCC	3.7.9a	User control center determines handover mode requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
61	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
62	Receive and process handover mode	NOCC and GS	3.7.10a	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
63	Generate and transmit carrier signal with frequency switching cmd on Ku-band forward link	GS	3.7.1a	Ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to user via TDRS, also for cmd to switch TDRS 1 frequency to TDRS 2 frequency and transmits via Ku-band forward link
64	Transpond carrier and freq. switching command	TDRS 1	3.7.2a	TDRS 1 receives forward link carrier and cmd signals, translates to UHF, amplifies signal and radiates UHF signal to user
65	Receive and process carrier signal and frequency switching command	User	3.7.3a	User detects carrier and cmd signals, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal; acquires PN code, bit, word, fram sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
66	Switch TDRS 1 frequency to TDRS 2 frequency	User	3.7.4a	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes cmd to switch frequency
67	Transmit TLM on TDRS 2 frequency	User	3.2.5	User sensors produce binary outputs, send TLM in real time, commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signal on TDRS 2 VHF freq.

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
68	Transpond user TLM on Ku-band return link	TDRS 2	3.2.7	TDRS 2 receives the VHF TLM, downconverts the VHF signal from each antenna, modulates Ku-band transmitter, and radiates signals on Ku-band link to ground
69	Receive and process user TLM	GS	3.2.3	Ground station acquires carrier lock, PN code, and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
70	Forward user TLM to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data, and acquires word and frame sync, and processes the data for display and input to orbit determination program; user now continues normal mission operations with TDRS 2
	TRANSFER DATA-LDR USER		(3.2)	
71	Generate and transmit cmd for user data	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
72	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
73	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
74	Transmit data command signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal
75	Transpond data cmd signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal, and radiates UHF signal to user
76	Receive and process data command signal	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal, and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
77	Generate and transmit user data	User	3.2.5	User sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signat at VHF
78	Transpond user data	TDRS	3.2.7	TDRS receives user data on VHF, downconverts VHF from each antenna, modulates Ku-band signals, and radiates Ku-band signals
79	Receive and process user data	GS	3.2.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
80	Transmit user data to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data, and acquires word and frame sync, and processes the data for displays and input to orbit determination program

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
	STATIONKEEPING LDR USER		(3.5a)	
81	Generate and transmit user stationkeeping cmd	UCC	3.5.15	UCC compute and develop delta-V maneuver requirements, define delta-V magnitude and time of execution, compute delta-V burn time, determine APS tank pressure and perf. data, generate and transmit delta-V burn time command
82	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
83	Receive and process stationkeeping command	NOCC and GS	3.5.16	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
84	Transmit delta-V maneuver command	GS	3.5.2	TDRS ground station receives real-time command, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits command signal
85	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, frame sync, removes error control code and compares transmitted with recovered signals as a check on ground systems
86	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time delay in transmitter, bitwise Mod-2 sum stored and recovered signals; if sum indicates no error, terminate transmission; if sum indicates error, generate and/or transmit a new command
87	Terminate transmission of correct command	GS	3.1.20	If sum indicates no error as above, computer ceases outputting cmd, modulator and PA are placed in standby, time of cmd cessation is logged and equipment status information is updated
88	Transpond delta-V maneuver command	TDRS	3.5.11	TDRS receives forward link Ku-band signal, translates to UHF, amplifies signal, and radiates UHF signal to user
89	Receive and process delta-V maneuver cmd	User	3.5.12 3.1.10 3.5.3	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F., and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; delta V register receives digital load (commanded delta V duration) and enters cmd into buffer storage; strips off error correcting or detecting code; telemeters delta V register load to ground (where GS confirms load and sends execute cmd) or user validates it on board (and sends to GS cmd error/rejection)
90	Perform delta-V maneuver	User	3.5.13 3.1.10 3.5.3 3.5.4	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, enables ASCS delta-V mode logic switch, sets/resets flipflops, delta-V register begins to count down, APS magnetic latching valve is energized, appropriate thruster valves actuated, and thrusters fired; ASCS delta-V control mode steers spacecraft attitude during burn, UCC monitors status during burn, user delta-V register enables delta-V cutoff switch, and disables delta-V mode, user re-enables ASCS mode, thrusters cease firing
91	Transmit execute verif. signal	User	3.5.14	User generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal at VHF
92	Transpond execute verification signal	TDRS	3.1.15	TDRS receives VHF signal, down converts signal from each antenna, modulates Ku-band transmitter and radiates Ku-band signal on Ku-band return link
93	Receive and process execut verif. signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verif. status to UCC and acquires word and frame sync, processes the data and isolates verification message and recognizes execute verification.

Table 2-5A. TDRS Operational Phase Sequence of Events (LDRS User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
94	Report execute verification to UCC	GS and UCC	3.1.17	Ground station performs verification command multiplexing, transmits verification command through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays command data
95	User decoder reject cmd	User	3.5.15	Instead of execute (3.5.13), user generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates transmitter and radiates RF signal at VHF
96	Transpond command reject	TDRS	3.1.15	TDRS receives VHF signal, downconverts signal from each antenna, modulates Ku-band transmitter, and radiates Ku-band signal as return link TLM
97	Receive and process command reject signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports command reject to UCC and acquires word and frame sync, processes data and isolates message, and recognizes command reject.
98	Forward command reject signal to UCC	GS	3.1.17	Ground station performs command reject multiplexing, transmits command reject signal through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays status data

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
	ACQUIRE MDR USER		(3.6b)	
201	Generate and transmit MDR user acquisition mode	UCC and NOCC	3.6.15a	User control center determines acquisition mode requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
202	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and developes scheduling program as inputs
203	Receive and process acquisition mode	NOCC and GS	3.6.16a	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and cmd generation
204	Generate and transmit carrier signal with frequency and VHF transmitter activation cmd	GS	3.6.1a	Ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to user via TDRS, also for cmds to activate the required frequency and the VHF transmitter, transmits via Ku-band forward link
205	Transpond carrier and commands	TDRS	3.6.2a	TDRS receives forward link Ku-band signals, translates to UHF, amplifies signal, and radiates UHF signal to user
206	Receive and process carrier and commands	User	3.6.3a	User detects carrier and cmd signals, acquires carrier lock, converts signal to I.F., and amplifies, demodulates signal; acquires PN code, bit, word, fram sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
207	Activate command frequency and VHF transmitter ON	User	3.1.11	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes command
208	Transmit return carrier and modulation	User	3.6.17a	User detects carrier, acquires carrier lock, converts signal to I.F., demodulates signal, acquires sync, starts return link carrier generator, modulates and radiates carrier with modulation on VHF return link
209	Transpond return carrier and modulation	TDRS	3.6.18a	TDRS receives the VHF carrier and modulation, downconverts VHF signal from each antenna, modulates Ku-band transmitter, and radiates carrier and modulation on Ku-band
210	Receive and process carrier and modulation	GS	3.6.19a	Ground station receives carrier and modulation, acquires carrier lock, acquires PN code, bit, word and frame sync, removes error control code, and can now send TDRS and user antenna commands on LDR link
211	Generate and transmit TDRS antenna program instructions on Ku fwd link	GS	3.6.2b	Ground station receives real-time antenna cmds from TDRSCON, decodes with high speed modem operation, buffers, and routes the data and generates cmd data code and applies PN code to carrier signals to TDRS, also for TDRS antenna cmds, transmits via Ku-band forward link
212	Receive and process antenna instructions and S/Ku beacon activation	TDRS	3.6.3b	TDRS detects cmd, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
213	Orient TDRS antenna to user for autotrack mode operation	TDRS	3.6.4b	TDRS enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops, and executes antenna cmd to point to user for autotrack mode and activates S- or Ku-band beacon
214	Transmit execute verification signal	TDRS	3.1.7	TDRS generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates Ku-band transmitter and radiates signal on Ku-band return link
215	Receive and process execute verification signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verification status to TDRSCON and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/Operation	Performed By	FF No.	Rationale
216	Report execute verification to TDRSCON	GS	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through N O C C comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at N O C C and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays cmd data
217	Transmit user antenna program instructions on Ku forward link	GS	3.6.2b	Ground station receives real-time antenna cmds from UCC, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to user via TDRS, also for user antenna cmds, transmits via Ku-band forward link
218	Transpond user antenna instructions with carrier on UHF forward link	TDRS	3.6.14b 3.6.2a	TDRS receives forward link Ku-band signals, translates to UHF, amplifies signals, and radiates UHF signals to user
219	Receive and process carrier and commands	User	3.6.15b 3.6.3a	User detects carrier and command signals, acquires carrier lock, converts signal to I.F., and amplifies, demodulates signal; acquires PN code, bit, word, fram sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
220	Orient user antenna to TDRS	User	3.6.16b 3.6.4b	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops, and executes antenna cmd to point to TDRS
221	Transmit execute verification signal	User	3.1.12	User generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal on VHF return link
222	Transpond execute verification signal	TDRS	3.1.15	TDRS receives VHF signal, downconverts signals from each antenna, modulates Ku-band transmitter and radiates Ku-band signal
223	Receive and process execute verification signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verification status to UCC and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification
224	Report execute verification to UCC	GS and UCC	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through N O C C comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed to N O C C and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays command data
225	Acquire S- or Ku-band beacon in autotrack mode	User	3.6.45b	MDR user now acquires the S- or Ku-band beacon signals from the TDRS and autotracks
226	Transmit carrier and modulation	User	3.6.41b	MDR user detects beacon signal, acquires carrier lock, converts signal to I.F., demodulates signal, acquires sync, starts return link carrier generator, modulates and radiates carrier with modulation on S- or Ku-band return link
227	Acquire autotrack on carrier	TDRS	3.6.42b	TDRS receives the carrier and modulation, and acquires autotrack on the carrier
228	Transpond carrier and modulation	TDRS	3.6.43b	TDRS receives the carrier and modulation, downconverts, modulates the Ku-band transmitter, and radiates the carrier and modulation on the Ku-band return link to ground
229	Receive and process user carrier and modulation	GS	3.6.44b	Ground station receives carrier and modulation, acquires carrier lock, acquires PN code, bit, word and frame sync, removes error control code and can now send PN code sequence to MDR user
230	Transmit PN code sequence	GS	3.6.27b	Power is put on ranging equipment, initial load is set into user PN code generator and clock is enabled to user PN code generator, and the modulator, transmitter and antenna selected for user ranging and radiates ranging signal to user via TDRS on Ku-band

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
231	Transpond user PN ranging code signal to user (forward link)	TDRS	3.6.29b	TDRS receives forward link Ku-band signal, translates and amplifies S or Ku-band signal, and radiates S- or Ku-band signal to user
232	Receive and process user PN code	User	3.6.30b 3.6.31b	User detects presence of carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit and frame sync, starts return link PN code generator, modulates transmitter with PN code, and activates TLM
233	Transmit user TLM	User	3.6.32b	User radiates telemetry to ground via TDRS on S- or Ku-band return link
234	Transpond user TLM	TDRS	3.1.15	TDRS receives TLM, downconverts, modulates Ku-band transmitter, and radiates Ku-band signal as return link TLM
235	Receive and process user TLM	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports TLM to UCC and acquires word and frame sync, processes the data for transmission to UCC or recording or just records and transmits the raw data to UCC
236	Forward the user TLM to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync, and processes the data for displays and input to orbit determination program; now can establish normal MDR mission operations
	COMMAND & CONTROL - MDR USER		(3.1a)	
237	Generate and transmit MDR user cmd	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
238	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
239	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
240	Transmit command signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal
241	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, frame sync, removes error control code and compares transmitted with recovered signals as a check on ground systems
242	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time decay in transmitter, bitwise Mod-2 sum stored and recovered signals; if sum indicates no error terminate transmission; if sum indicates error, generate and/or transmit a new command
243	Terminate transmission of correct command	GS	3.1.20	If sum indicates no error, as above, computer ceases outputting cmd, modulator and PA are placed in standby, time of cmd cessation is logged and equipment status information is updated
244	Transpond command signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates and amplifies S- or Ku-band signal, and radiates S- or Ku-band signal to user
245	Receive and process command	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
246	Execute command	User	3.1.11	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes cmd
247	Transmit execute verification signal	User	3.1.12	User generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operations	Performed By	FF No.	Rationale
248	Transpond execute verification signal	TDRS	3.1.15	TDRS receives S- or Ku-band signal, translates S- or Ku-band signal, modulates Ku-band transmitter, and radiates Ku-band signal to ground
249	Receive and process execute verif. signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verification status to UCC and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification
250	Report execute verification to UCC	GS and UCC	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed to NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays command data
251	User decoder reject command	User	3.1.13	Instead of execute (3.1.11), user generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates transmitter and radiates RF signal on S- or Ku-band
252	Transpond command reject	TDRS	3.1.15	TDRS receives S- or Ku-band signal, translates S- or Ku-band signal, modulates Ku-band transmitter, and radiates Ku-band signal
253	Receive and process command reject	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports command reject to UCC and acquires word and frame sync, processes data and isolates message, and recognizes command reject
254	Forward command reject signal to UCC	GS	3.1.17	Ground station performs command reject multiplexing, transmits s command reject through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays status data
	TRACK AND RANGE - MDR USER		(3.3b)	(Assumes initial acquisition completed)
255	Generate and transmit user tracking mode	UCC and NOCC	3.3.13	User control center determines tracking requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
256	Receive and process tracking mode	NOCC and GS	3.3.14	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
257	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
258	Generate and transmit TDRS S-band or Ku-band antenna pointing commands	TDRSCON and GS	3.3.15	Ground station receives real-time antenna cmds from TDRSCON, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to TDRS also for TDRS antenna cmds, transmits via forward link
259	Receive and process S or Ku-band antenna commands	TDRS	3.1.5	TDRS detects carrier, unsquelches receiver, acquires carrier lock, converts signals to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
260	Orient TDRS antenna to user	TDRS	3.1.6	TDRS enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes antenna cmd to point to user
261	Transmit antenna pointing status (TLM)	TDRS	3.3.16 3.1.7	TDRS generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates Ku-band transmitter and radiates signal on Ku-band return link
262	Receive and process antenna status	GS	3.3.17	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports status to TDRSCON and acquires word, and frame sync, processes data and isolates status message and recognizes execute of antenna pointing

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
263	Report antenna status to TDRSCON	GS	3.3.18	Ground station performs status cmd multiplexing, transmits status through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays cmd data
264	Generate and transmit user PN ranging code signals	GS	3.3.2	Power is put on ranging equipment, initial load is set into TDRS and user PN code generators and clock is enabled to TDRS and user PN code generators and the modulator,transmitter and antenna selected for TDRS and user ranging and radiates ranging signal to TDRS and user on Ku-band (or on the S-band tracking link, or on VHF if on backup TT&C link)
265	Transpond user ranging code signal to user (forward link)	TDRS	3.3.7	TDRS receives forward link Ku-band signal, translates and amplifies signal, and radiates to user
266	Transpond user ranging code return signal to TDRS (return link)	User	3.3.9	User detects presence of carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquares PN code sync, starts return link PN code generator, modulates transmitter with PN code, and radiates RF signal at S- or Ku-band
267	Transpond user ranging code return signal to ground (return link)	TDRS	3.3.4	TDRS receives S- or Ku-band signal from user, translates and modulates Ku-band transmitter and radiates Ku-band signal to ground
268	Transpond TDRS ranging code return signal to ground (return link)	TDRS	3.3.4 3.3.21	TDRS receives Ku-band signal, acquires coherency of return-to-forward links, translates PN code to other Ku-band freq. and modulates Ku-band transmitter and radiates Ku-band signal to the ground station; may also convert Ku-band signal to S-band and reradiate PN code then perform trilateration operation; Tracking Stations 1 and 2 receive the TDRS S-band range code, acquire PN code sync, apply PN codes 1 and 2, transmit signals to TDRS at S-band, TDRS receives S-band signals from Tracking Stations 1 and 2, converts to Ku-band, modulates the Ku-band transmitter and radiates Ku-band signal to the ground station; or TDRS may receive S-band ranging signals by initial tri-lateration operations of the tracking stations, with return S-band transponded directly to the Tracking Stations 1 and 2 and reported to the ground station via NASCOM; TDRS may also receive VHF signal on the backup TT&C link, downconvert from each antenna, modulate the Ku-band transmitter, and radiate Ku-band signal to the ground station
269	Receive and process TDRS and user tracking data	GS	3.3.5	Ground station acquires carrier lock, acquires TDRS and user PN range code sync, measures two-way time delay and doppler for GS-TDRS and GS-user links, and formats and time tags the data
270	Report tracking data to user and TDRS control centers	GS	3.3.6	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to control centers via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync and processes the data for displays and input to orbit determination program
	MONITOR & CONTROL - MDR USER (HOUSEKEEPING)		(3.4a)	
271	Generate and transmit user cmd for housekeeping	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, send to NOCC comm processor
272	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
273	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
274	Transmit housekeeping cmd	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
275	Transpond housekeeping cmd (forward link)	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates and amplifies signal and radiates S- or Ku-band signal to user
276	Receive and process housekeeping cmd	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
277	Generate and transmit housekeeping	User	3.4.7	User housekeeping sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signal at S- or Ku-band
278	Transpond user housekeeping	TDRS	3.4.9	TDRS receives S- or Ku-band signal, translates and modulates Ku-band signal, and radiates Ku-band signal
279	Receive and process user housekeeping	GS	3.4.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
280	Transmit user housekeeping to UCC	GS and UCC	3.4.5	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync, and processes the data for displays and input to orbit determination program
281	Compare housekeeping to reference and evaluate	UCC	3.4.4	UCC compares input housekeeping data to stored reference data, evaluates for correctness of performance and sends new command request if required to correct
	TRANSFER DATA - MDR USER		(3.2)	
282	Generate and transmit cmd for user data	UCC and NOCC	3.1.2	User control center determines command requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
283	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
284	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
285	Transmit data command signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal
286	Transpond data cmd signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates and amplifies signal, and radiates S- or Ku-band signal to user
287	Receive and process data command signal	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal, and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
288	Generate and transmit user data	User	3.2.5	User sensors produce binary outputs, send data in real time (on record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signals at S- or Ku-band
289	Transpond user data	TDRS	3.2.7	TDRS receives user data, translates and modulates Ku-band signals, and radiates Ku-band signals
290	Receive and process user data	GS	3.2.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
291	Transmit user data to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data, and acquires word and frame sync, and processes the data for displays and input to the orbit determination program

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
	HANDOVER - MDR USER		(3.7b)	
292	Generate and transmit MDR user handover mode	UCC and NOCC	3.7.9b	User control center determines handover mode requirements and priority status, provides spaceccraft orbital parametrics, sends to NOCC comm processor
293	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
294	Receive and process handover mode	NOCC and GS	3.7.10b	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and cmd generation
295	Generate and transmit TDRS 2 antenna cmds	GS	3.6.2b	Ground station receives real-time antenna cmds from TDRSCON, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to TDRS 2, also for TDRS antenna cmds, transmits via Ku-band forward link to TDRS 2
296	Receive and process antenna commands and activate S- or Ku-band beacon	TDRS 2	3.6.3b	TDRS 2 detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
297	Orient TDRS 2 antenna to user for autotrack mode operation	TDRS 2	3.6.4b	TDRS 2 enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops, and executes antenna cmd to point to user for autotrack mode, and activates S- or Ku-band beacon
298	Transmit execute verification signal	TDRS 2	3.1.7	TDRS 2 generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates Ku-band transmitter and radiates signal on Ku-band return link
299	Receive and process execute verification signal	GS	3.1.16	Ground station acquires carrier lock, PN code, and bit sync, removes error control code, reports verification status to TDRSCON and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification
300	Report execute verification to TDRSCON	GS	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays cmd data
301	Transmit user antenna cmds with carrier	GS	3.6.12b	Ground station receives also real-time antenna cmds from UCC, decodes with high speed modem operation, buffers and routes the data and generates cmd data code and applies PN code to carrier signals to user via TDRS, also for user antenna cmds and transmits via Ku-band fwd link
302	Transpond user antenna cmds	TDRS 1	3.6.14b	TDRS 1 receives forward link Ku-band signals, translates to UHF, amplifies signals, and radiates UHF signals to user
303	Receive and process carrier and commands	User	3.6.15b 3.6.3a	User detects carrier and cmd signals, acquires carrier lock, converts signal to I.F., and amplifies, demodulates signal; acquires PN code, bit, word, frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
304	Orient user antenna to TDRS 2	User	3.6.16b 3.6.4b	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops, and executes antenna cmd to point to TDRS 2
305	Transmit execute verification signal	User	3.1.12	User generates val map, commutates val map into telemetry stream, applies error control conding and PN code, modulates transmitter and radiates signal on VHF return link
306	Transpond execute verif. signal	TDRS 2	3.1.15	TDRS 2 receives VHF signal, downconverts and modulates Ku-band transmitter and radiates Ku-band signal

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event Operation	Performed By	FF No.	Rationale
307	Receive and process execute verif signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verification status to UCC and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification
308	Report execute verification to UCC	GS and UCC	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through NOCC comm processor to UCC via NASCOM (with modem) and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays command data
309	Acquire S- or Ku-band beacon in autotrack mode	User	3.6.45b	MDR user now acquires the S- or Ku-band beacon signals from the TDRS and autotracks
310	Transmit carrier and modulation	User	3.6.41b	MDR user detects beacon signal, acquires carrier lock, converts signal to I.F., demodulates signal, acquires sync, starts return link carrier generator, modulates and radiates carrier with modulation on S- or Ku-band return link
311	Acquire autotrack on carrier	TDRS	3.6.42b	TDRS receives the carrier and modulation, and acquires autotrack on the carrier
312	Transpond carrier and modulation	TDRS	3.6.43b	TDRS receives the carrier and modulation, downconverts, modulates the Ku-band transmitter, and radiates the carrier and modulation on the Ku-band return link to ground
313	Receive and process user carrier and modulation	GS	3.6.44b	Ground station receives carrier and modulation, acquires carrier lock, acquires PN code, bit, word and frame sync, removes error control code and can now send PN code sequence to MDR user
314	Transmit PN code sequence	GS	3.6.27b	Power is put on ranging equipment, initial load is set into user PN code generator and clock is enabled to user PN code generator, and the modulator, transmitter and antenna selected for user ranging and radiates ranging signal to user via TDRS on Ku-band
315	Transpond user PN ranging code signal to user (forward link)	TDRS	3.6.29b	TDRS receives forward link Ku-band signal, translates and amplifies S- or Ku-band signal, and radiates S- or Ku-band signal to user
316	Receive and process user PN code	User	3.6.30b 3.6.31b	User detects presence of carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit and frame sync, starts return link PN code generator, modulates transmitter with PN code and activates TLM
317	Transmit user TLM	User	3.6.32b	User radiates telemetry to ground via TDRS on S- or Ku-band return link
318	Transpond user TLM	TDRS	3.1.15	TDRS receives TLM, downcoverts, modulates Ku-band transmitter, and radiates Ku-band signal as return link TLM
319	Receive and process user TLM	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports TLM to UCC and acquires word and frame sync, processes the data for transmission to UCC or recording or just records and transmits the raw data to UCC
320	Forward the user TLM to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync, and processes the data for displays and input to orbit determination program; now can establish normal MDR mission operations
	TRANSFER DATA - MDR USER		(3.2)	
321	Generate and transmit cmd for user data	UCC and NOCC	3.1.2	User control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
322	Provides status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
323	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
324	Transmit data command signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event Operation	Performed By	FF No.	Rationale
325	Transpond data command signal	TDRS	3.1.9	TDRS receives forward link Ku-band signal, translates and amplifies signal and radiates S- or Ku-band signal to user
326	Receive and process data cmd signal	User	3.1.10	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal, and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
327	Generate and transmit user data	User	3.2.5	User sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signals at S- or Ku-band
328	Transpond user data	TDRS	3.2.7	TDRS receives user data, translates and modulates Ku-band signals, and radiates Ku-band signals
329	Receive and process user data	GS	3.2.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to UCC or recording, or just records and transmits the raw data to UCC
330	Transmit user data to UCC	GS and UCC	3.2.4	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data, and acquires word and frame sync, and processes the data for displays and input to the orbit determination program
	STATIONKEEPING - MDR USER		(3.5a)	
331	Generate and transmit user stationkeeping command	UCC	3.5.15	UCC compute and develop delta-V maneuver requirements, define delta-V magnitude and time of execution, compute delta-V burn time, determine APS tank pressure and perf. data, generate and transmit delta-V burn time
332	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
333	Receive and process stationkeeping cmd	NOCC and GS	3.5.16	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and cmd generation
334	Transmit delta-V maneuver cmd	GS	3.5.2	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data and generates cmd data code, applies PN code to cmd signal to user via TDRS, transmits cmd signal
335	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, frame sync, removes error control code and compares transmitted with recovered signals as a check on ground stations
336	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time delay in transmitter, bitwise Mod-2 sum stored and recovered signals; if sum indicates no error, terminate transmission; if sum indicates error, generate and/or transmit a new cmd
337	Terminate transmission of correct cmd	GS	3.1.20	If sum indicates error, as above, computer ceases outputting cmd, modulation and PA are placed in standby, time of cmd cessation is logged, and equipment status information is updated
338	Transpond delta-V maneuver command	TDRS	3.5.11	TDRS receives forward link Ku-band signal, translates and amplifies signal, and radiates S- or Ku-band signal to user
339	Receive and process delta-V maneuver command	User	3.5.12 3.1.10 3.5.3	User detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; delta-V register receives digital load (commanded delta-V duration) and enters cmd into buffer storage; strips off error correcting or detecting code; telemeters delta-V register load to ground (where GS confirms load and sends execute cmd) or user validates it on board (and sends to GS cmd error/rejection)
340	Perform delta-V maneuver	User	3.5.13 3.1.10 3.5.3 3.5.4	User enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, enables ASCS delta-V mode logic switch, sets/resets flip-flops, delta-V register begins to count down, APS magnetic latching valve is energized, appropriate thruster valves actuated, and thrusters fired; ASCS delta-V control mode steers S/C attitude during burn, UCC monitors status during burn, user delta-V register enables delta-V cutoff switch and disables delta-V mode, user re-enables ASCS mode, thrusters cease firing

Table 2-5B. TDRS Operational Phase Sequence of Events (MDR User Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
341	Transmit execute verif. signal	User	3.5.14	User generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal at S- or Ku-band
342	Transpond execute verification signal	TDRS	3.1.15	TDRS receives S- or Ku-band signal, translates and modulates Ku-band transmitter, and radiates Ku-band signal on Ku-band return link
343	Receive and process verif. signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verif. status to UCC and acquires word and frame sync, processes the data and isolates verification message and recognizes execute verification
344	Report execute verif. to UCC	GS and UCC	3.1.17	Ground station performs verif. cmd multiplexing, transmits verif. cmd through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays cmd data
345	User decoder reject signal	User	3.5.15	Instead of execute (3.5.13), user generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates transmitter and radiates RF signal on S- or Ku-band
346	Transpond command reject	TDRS	3.1.15	TDRS receives S- or Ku-band signal, translates and modulates Ku-band transmitter, and radiates Ku-band signal as return link TLM
347	Receive and process command reject signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports command reject to UCC and acquires word and frame sync, processes data and isolates verif. message and recognizes command reject
348	Forward command reject signal to UCC	GS	3.1.17	Ground station performs command reject multiplexing, transmits command reject signal through NOCC comm processor to UCC via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; UCC acquires word and frame sync, processes data and records and displays status data

Table 2-5C. TDRS Operational Phase Sequence of Events (TDRS Operations)

No.	Function/Event/ Operations	Performed By	FF No.	Rationale
	COMMAND & CONTROL - TDRS		(3.1b)	
401	Generate and transmit TDRS cmd	TDRSCON & NOCC	3.1.2	TDRS control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
402	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files and develops scheduling program as inputs
403	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and cmd generation
404	Transmit command signal	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to TDRS, transmits cmd signal
405	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, fram sync, removes error control code and compares transmitted with recovered signals as a check on ground systems
406	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time delay in transmitter, bitwise Mod-2 sum stored and recovered signals; if sum indicates no error, terminate transmission; if sum indicates error, generate and/or transmit a new cmd
407	Terminate transmission of correct cmd	GS	3.1.20	If sum indicates error, as above, computer ceases outputting cmd, modulator and PA are placed in standby, time of command cessation is logged and equipment status information is updated
408	Receive and process command	TDRS	3.1.5	TDRS detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word, and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution

Table 2-5C. TDRS Operational Phase Sequence of Events (TDRS Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
409	Execute command	TDRS	3.1.6	TDRS enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, sets/resets flipflops and executes command
410	Transmit execute verification signal	TDRS	3.1.7	TDRS generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates Ku-band transmitter and radiates signal on Ku-band return link
411	Receive and process execute verif. signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verification status to TDRSCON and acquires word and frame sync, processes data and isolates verification message and recognizes execute verification
412	Report execute verification to TDRSCON	GS	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays cmd data
413	TDRS decoder reject command	TDRS	3.1.8	Instead of execute (3.1.6), TDRS generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates Ku-band transmitter and radiates RF signal on Ku-band return link
414	Receive and process command reject	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports command reject to TDRSCON and acquires word and frame sync, processes data and isolates message and recognizes command reject
415	Forward cmd reject signal to TDRSCON	GS	3.1.17	Ground station performs command reject multiplexing, transmits command reject through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays status data
	TRACK & RANGE - TDRS		(3.3c)	
416	Generate and transmit TDRS tracking mode	TDRSCON & NOCC	3.3.13	TDRS control center determines tracking requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
417	Receive and process tracking mode	NOCC and GS	3.3.14	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
418	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
419	Generate and transmit TDRS PN ranging code signal to TDRS	GS	3.3.2	Power is put on ranging equipment, initial load is set into TDRS PN code generator and clock is enabled to TDRS PN code generator and the modulator, transmitter and antenna selected for TDRS ranging and radiates ranging signal on Ku-band (or on the S-band tracking link, or on VHF if on backup TT&C link)
420	Transpond TDRS ranging code return signal (return link)	TDRS	3.3.4 3.3.19	TDRS receives Ku-band signal, acquires coherency of return-to-forward links, translates PN code to other Ku-band freq., and modulates Ku-band transmitter and radiates Ku-band signal to the ground station; may also convert Ku-band signal to S-band and reradiate PN code, then perform tri-lateration operation; Tracking Stations 1 and 2 receive the TDRS S-band range code, acquire PN code sync, apply PN code 1 and 2, transmit signals to TDRS at S-band, TDRS receives S-band signals from Tracking Stations 1 and 2, converts to Ku-band, modulates the Ku-band transmitter and radiates Ku-band signal to the ground station; or TDRS may receive S-band ranging signals by initial tri-lateration operation of the tracking stations, with return S-band transponded directly to the Tracking Stations 1 and 2 and reported to the ground station via NASCOM; TDRS may also receive VHF ranging signal on the backup TT&C link, downconvert from each antenna, modulate the Ku-band transmitter, and radiate Ku-band signal to the ground station
421	Receive and process TDRS tracking data	GS	3.3.5	Ground station acquires carrier lock, acquires TDRS PN range code sync, measures two-way time delay and doppler for GS-TDRS link, and formats and time tags the data
422	Report tracking data to TDRS control center		3.3.6	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to control center via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync and processes the data for displays and input to orbit determination program

Table 2-5C. TDRS Operational Phase Sequence of Events (TDRS Operations) (Cont)

No.	Function/Event/ Operations	Performed By	FF No.	Rationale
	MONITOR & CONTROL (HOUSEKEEPING)-TDRS		(3.4b)	
423	Generate and transmit TDRS cmd for housekeeping	TDRSCON & NOCC	3.1.2	TDRS control center determines cmd requirements and priority status, provides spacecraft orbital parametrics, sends to NOCC comm processor
424	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
425	Receive and process command	NOCC and GS	3.1.4	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and command generation
426	Transmit housekeeping command	GS	3.1.14	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to TDRS, transmits cmd signal
427	Receive and process housekeeping cmd	TDRS	3.1.5	TDRS detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; enters cmd into buffer storage, strips off error correcting or detecting code, checks for validity before execution
428	Generate and transmit housekeeping	TDRS	3.4.2	TDRS housekeeping sensors produce binary outputs, send data in real time (or record on tape), commutate data, apply error control code, PN code and modulate transmitter, and radiate RF signal at Ku-band return link
429	Receive and process TDRS housekeeping	GS	3.4.3	Ground station acquires carrier lock, PN code and bit sync, removes error control code, and either acquires word sync, frame sync and processes the data for transmission to TDRSCON or recording, or just records and transmits the raw data to TDRSCON
430	Transmit TDRS housekeeping to TDRSCON	GS and TDRSCON	3.4.5	Ground station performs TLM processing and multiplexing, transmits data through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and performs TLM processing and demultiplexing, records the data and acquires word and frame sync, and processes the data for displays and input to orbit determination program
431	Compare housekeeping to reference and evaluate	TDRSCON	3.4.4	TDRSCON compares input housekeeping data to stored reference data, evaluates for correctness of performance, and sends new command request if required to correct
	STATIONKEEPING-TDRS		(3.5b)	
432	Generate and transmit TDRS stationkeeping command	TDRSCON	3.5.15	TDRSCON compute and develop delta-V maneuver requirements, define delta-V magnitude and time of execution, compute delta-V burn time, determine APS tank pressure and perf. data, generate and transmit delta-V burn time command
433	Provide status, orbit data and scheduling	NOCC	3.1.3	NOCC generates orbital predicts or retrieves status data from history files, and develops scheduling program as inputs
434	Receive and process stationkeeping cmd	NOCC and GS	3.5.16	NOCC comm processor receives cmds, multiplexes and priority routes cmds, encodes data with high speed modem, NASCOM sends to ground station for processing and cmd generation
435	Transmit delta-V maneuver cmd	GS	3.5.2	TDRS ground station receives real-time cmd, decodes with high speed modem operation, buffers and routes the data, and generates cmd data code, applies PN code to cmd signal to TDRS, transmits cmd signal
436	Demodulate transmitted signal	GS	3.1.18	Ground station taps off portion of energy, converts to I.F., acquires carrier lock, and acquires PN code, bit, word, frame sync, removes error control code and compares transmitted with recovered signals as a check on ground systems
437	Compare transmitted and recovered signals	GS	3.1.19	Ground station compensates for time delay in transmitter, bitwise Mod-2 sum stored and recovered signals; if sum indicates no error, terminate transmission; if sum indicates error, generate and/or transmit a new command
438	Terminate transmission of correct cmd	GS	3.1.20	If sum indicates no error, as above, computer ceases outputting cmd, modulator and PA are placed in standby, time of cmd cessation is logged, and equipment status information is updated
439	Receive and process delta-V maneuver command	TDRS	3.5.3 3.5.10 3.5.12	TDRS detects carrier, unsquelches receiver, acquires carrier lock, converts signal to I.F. and amplifies, demodulates signal and acquires PN code, bit, word and frame sync; delta-V register receives digital load (commanded delta-V duration) and enters cmd into buffer storage; strips off error correcting or detecting code; telemeters delta-V register load to ground (where GS confirms load and sends execute cmd) or TDRS validates it on board (and sends to GS cmd error/rejection)

Table 2-5C. TDRS Operational Phase Sequence of Events (TDRS Operations) (Cont)

No.	Function/Event/ Operation	Performed By	FF No.	Rationale
440	Perform delta-V maneuver	TDRS	3.5.4 3.1.11 3.5.3	TDRS enables cmd decoder, enters cmd into cmd decoder input buffer, decodes cmd, enables ASCS delta-V mode logic switch, sets/resets flip-flops, delta-V register begins to count down, APS magnetic latching valve is energized, appropriate thruster valves actuated, and thrusters fired; ASCS delta-V control mode steers S/C attitude during burn, TDRSCON monitors status during burn, TDRS delta-V register enables delta-V cutoff switch, and disables delta-V mode, TDRS re-enables ASCS mode, thrusters cease firing
441	Transmit execute verif. signal	TDRS	3.5.5	TDRS generates val map, commutates val map into telemetry stream, applies error control coding and PN code, modulates transmitter and radiates signal
442	Receive and process execute verification signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports verif. status to TDRSCON and acquires word and frame sync, processes the data and isolates verification message and recognizes execute verification
443	Report execute verif. to TDRSCON	GS and TDRSCON	3.1.17	Ground station performs verification cmd multiplexing, transmits verification cmd through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes cmd or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays cmd data
444	TDRS decoder reject command	TDRS	3.5.8	Instead of execute (3.5.4), TDRS generates nonval map, commutates nonval map into TLM stream, applies error control code to TLM stream, applies PN code to TLM stream, modulates transmitter and radiates RF signal
445	Receive and process cmd reject signal	GS	3.1.16	Ground station acquires carrier lock, PN code and bit sync, removes error control code, reports command reject to TDRSCON and acquires word and frame sync, processes data and isolates message, and recognizes command reject
446	Forward command reject signal to TDRSCON	GS	3.1.17	Ground station performs command reject signal multiplexing, transmits command through NOCC comm processor to TDRSCON via NASCOM (with modem), and acquires bit sync and demultiplexes status or the multiplexed data are just displayed at NOCC and reported via orderwire; TDRSCON acquires word and frame sync, processes data and records and displays status data

For MDR User tracking, acquisition and handover, the sequences involve antenna pointing operations of both the User and TDRS, for which commands may be transmitted simultaneously. For MDR acquisition it is essential to establish the UHF forward link to the User and VHF return link from the User before commands can be transmitted and received. After this LDR link is established (the same sequence of operations as in LDR User acquisition), and the VHF and MDR transmitters and S/Ku-band beacon are activated, then the TDRS and MDR User antenna programs may be transmitted for operational implementation.

To achieve a representative sequence and flow of operations, some operations performed early need not be repeated later. For example, acquisition operations are performed prior to tracking operations, so the antenna operations performed in acquisition are not repeated in tracking, Moreover, in tracking, acquisition and handover operations, the sequence of operations includes comprehensive antenna programs and commands for implementation; in actuality the system may permit considerable planning, computing, scheduling, and preprogramming of operational sequences to be implemented at appropriate times and locations of the User spacecraft in their mission trajectories. The operational sequences may be reduced accordingly. Similarly, to the extent that the results of the performance commanded by themselves act as a verification of that performance, the sequence of verification operations may be reduced.

In handover, storage of preprogrammed commands, or new command sent to the User during its first TDRS FOV for implementation when it enters the second TDRS FOV, etc., may be required. MDR User handover may require preprogrammed or commanded antenna search, pointing and lock-on and autotracking operational capabilities.

2.3 SYSTEM RELIABILITY ANALYSIS

The major reliability goal in the TDRS design effort was to provide a satellite reliability of 0.8. This goal was established in conjunction with the GSFC Project Office after preliminary reliability analyses showed the relationship between satellite reliability and the probability of having one or two satellites remaining at the end of five years. This relationship is shown in Figure 2-83 which also shows the effects of the original number of satellites purchased. In developing the curves a booster reliability of 0.95 and an apogee motor reliability of 0.98 were used.

The curves show the probability of mission success where mission success is defined as the ability of each TDRS to service 20 LDR users and 2 MDR users on the return link and 2 LDR and 2 MDR users simultaneously on the forward link. Reduced forward link capability is permitted during eclipse. This capability exceeds that required in the statement of work and a higher probability of success can be obtained using the SOW capability required of 1 MDR user on forward and return and 1 LDR user on forward link. An even higher reliability will occur for reduced operations below the SOW capability since the satellite in nearly all cases degrades gracefully allowing mission continuation.

Subsystem reliability analyses show that for the excess capability discussed above, the satellite reliability is 0.804 and for the SOW capability the satellite reliability is 0.844. Detail subsystem analysis is given in Section 10.0.

Table 2-6 shows the system reliabilities taken from Figure 2-83 of 1 or 2 spacecraft remaining in full operation at the end of five years for these satellite reliabilities.

Table 2-6. Probability of Mission Success

	Probability of Success			
Satellite Capability	Excess Capability		SOW Capability	
No. S/C in Full Operation	1	2	1	2
Initial No. of Satellites				
3	.983	.840	.990	.880
4	.996	.950	.998	.965
5	.999	.983	.9995	.991

These high goals were achieved by adhering to a design philosophy throughout the spacecraft of eliminating or minimizing single point failures, using high reliability components, and using redundancy whenever necessary. The weight margins provided by the creative and unique design approaches permitted the use of redundancy in all critical areas.

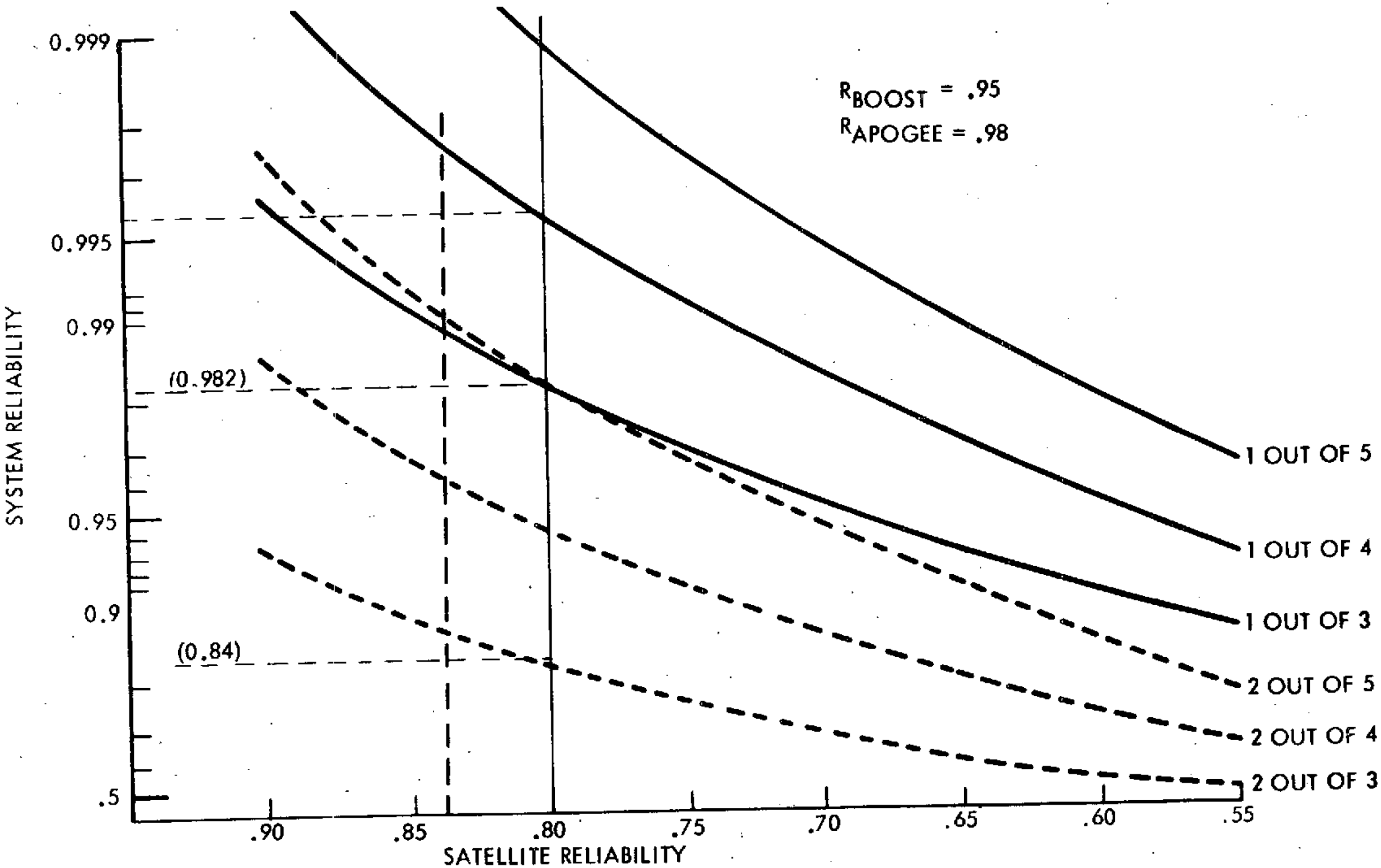

Figure 2-83. Relationship Between Satellite and System Reliability